Cottage Line Dune Integrity Assessment

Presented to:

City of Norfolk, Department of Public Works

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Table of Contents

1. Introduction 1
2. Approach 5
3. Storm Waves and Water Levels 6
 3.1. Water Levels 6
 3.2. Wave Heights and Periods 8
4. Beach Profile Change Modeling 11
 4.1. Introduction 11
 4.2. Sediment Characteristics 11
 4.3. Existing Conditions Dune Erosion Potential 12
 4.4. Impact of Dune Modifications 18
5. Summary and Conclusions 26
6. References 28
Appendix A: Existing Condition Beach and Dune Profiles
Appendix B: SBEACH Storm Erosion Results, Existing Conditions
Appendix C: SBEACH Storm Erosion Results, +18 ft NAVD88 Maximum Dune Crest Elevation
Appendix D: SBEACH Storm Erosion Results, +17 ft NAVD88 Maximum Dune Crest Elevation
Appendix E: SBEACH Storm Erosion Results, +16 ft NAVD88 Maximum Dune Crest Elevation
Appendix F: SBEACH Storm Erosion Results, +15 ft NAVD88 Maximum Dune Crest Elevation
Appendix G: SBEACH Storm Erosion Results, +14 ft NAVD88 Maximum Dune Crest Elevation
Appendix H: SBEACH Storm Erosion Results, +12 ft NAVD88 Maximum Dune Crest Elevation

Table of Figures

Figure 1: Location of Cottage Line dune integrity assessment site 2

Figure 2: Typical elements of bay beach and dune (from Hardaway et al., 2001) 3

Figure 3: Measured significant wave heights at Norfolk wave gage and water levels at Sewells Point, 2009 nor'easter 9

Figure 4: Model significant wave heights in Chesapeake Bay and measured water levels at Sewells Point, August 1933 hurricane 9

Figure 5: Estimated significant wave heights at Norfolk wave gage and water levels at Sewells Point, Hurricane X 10

Figure 6: Estimated significant wave heights at Norfolk wave gage and water levels at Sewells Point, Hurricane Y 10

Figure 7: Illustration of dune volume definition and dune erosion classifications 12

Figure 8: SBEACH results at 3rd Bay St. for existing dune 14

Figure 9: SBEACH results at Beach View St. for existing dune 15

Figure 10: SBEACH results east of Cape View Ave. for existing dune 15

Figure 11: SBEACH results between Inlet Rd. and 1st Bay St. for dune crest at +12 ft NAVD88 22

Figure 12: SBEACH results between Inlet Rd. and 1st Bay St. for dune crest at +17 ft NAVD88 22

Figure 13: Dune elevations around transect 268+68 between Inlet Rd. and 1st Bay St. 23

Figure 14: Flood damage potential vs. dune volumes and peak wave crest elevations 24

Figure 15: Peak wave crest elevations for SBEACH storms with dune volumes 24

List of Tables

Table 1: Peak Water Levels for Storms and FEMA / USACE Stillwater Elevations 7

Table 2: SBEACH Model Dune Erosion – Existing Conditions 13

Table 3: Existing Dune Volume Above +8 ft NAVD88 and Within Frontal Dune Reservoir 16

Table 4: SBEACH Model Dune Erosion – Modified Dune in 2009 Nor'easter.................................. 19

Table 5: SBEACH Model Dune Erosion – Modified Dune in 1933 August Hurricane 19

Table 6: SBEACH Model Dune Erosion – Modified Dune in Hurricane X (0.5% Annual Chance) .. 20

Table 7: SBEACH Model Dune Erosion – Modified Dune in Hurricane Y (0.5% Annual Chance) .. 20

1. Introduction

Moffatt & Nichol was retained by the City of Norfolk on February 27, 2014 to provide coastal engineering support services relative to a dune integrity assessment along a reach of the Ocean View shoreline on the Chesapeake Bay in Norfolk, Virginia. This section of Ocean View shoreline is known locally as Cottage Line, with a short extension into East Ocean View. The dune integrity assessment study is required in order to estimate the potential impacts of man-made alterations to the dune morphology requested / proposed by property owners in the project area.

For the purposes of this report, "Cottage Line" refers to the reach of Ocean View shown in Figure 1, extending from Warwick Avenue to 3rd Bay Street. Present-day primary dune crest elevations in Cottage Line are between +14 and +22 feet NAVD88. In general, the dune crest and back slope are densely vegetated with well-established dune plants. Landward of the primary dune are a line of residential (habitable) structures. At some positions, the seaward edge of these structures is located on the back slope of the primary dune, while at other positions the structures are located well back from the primary dune.

Regular, twice-yearly topographic surveys indicate that the dune crest elevations in Cottage Line have been relatively stable – and in some locations, increasing – since regular beach profile monitoring was begun in 2005. However, there were periods between 2005 and 2013 when the crest elevation decreased between surveys at some Cottage Line transects. Although Hurricane Irene impacted the area in August 2011, there were no indications of severe lingering impacts to the beach and dune system in Cottage Line. This indicates that the dune system is well-established and that this beach is generally able to recover from moderate storm impacts without intervention.

Figure 2 illustrates typical elements of beach and dune profiles (beach berm, primary dune, etc.) and their positions relative to each other. It is noted that not all locations in the bay will have all of these elements present; for example, developed shorelines often lack many of the features landward of the primary dune, due to the presence of hotels, condominiums, and other structures and infrastructure. From right to left (bayward to landward) in the figure, the shallow submerged nearshore area transitions up onto the beach berm, a mildly-sloped expanse of sand that is mostly clear of vegetation. Beaches are naturally shaped by the action of water in the form of tides and waves; dunes are naturally shaped (mainly) by winds acting on dry sand from the beach berm and other dunes.

This study is concerned with the erosion resistance and flood mitigation provided by the primary dune and land immediately behind (leeward of) the primary dune, since property development generally begins in Cottage Line just landward of the primary dune.

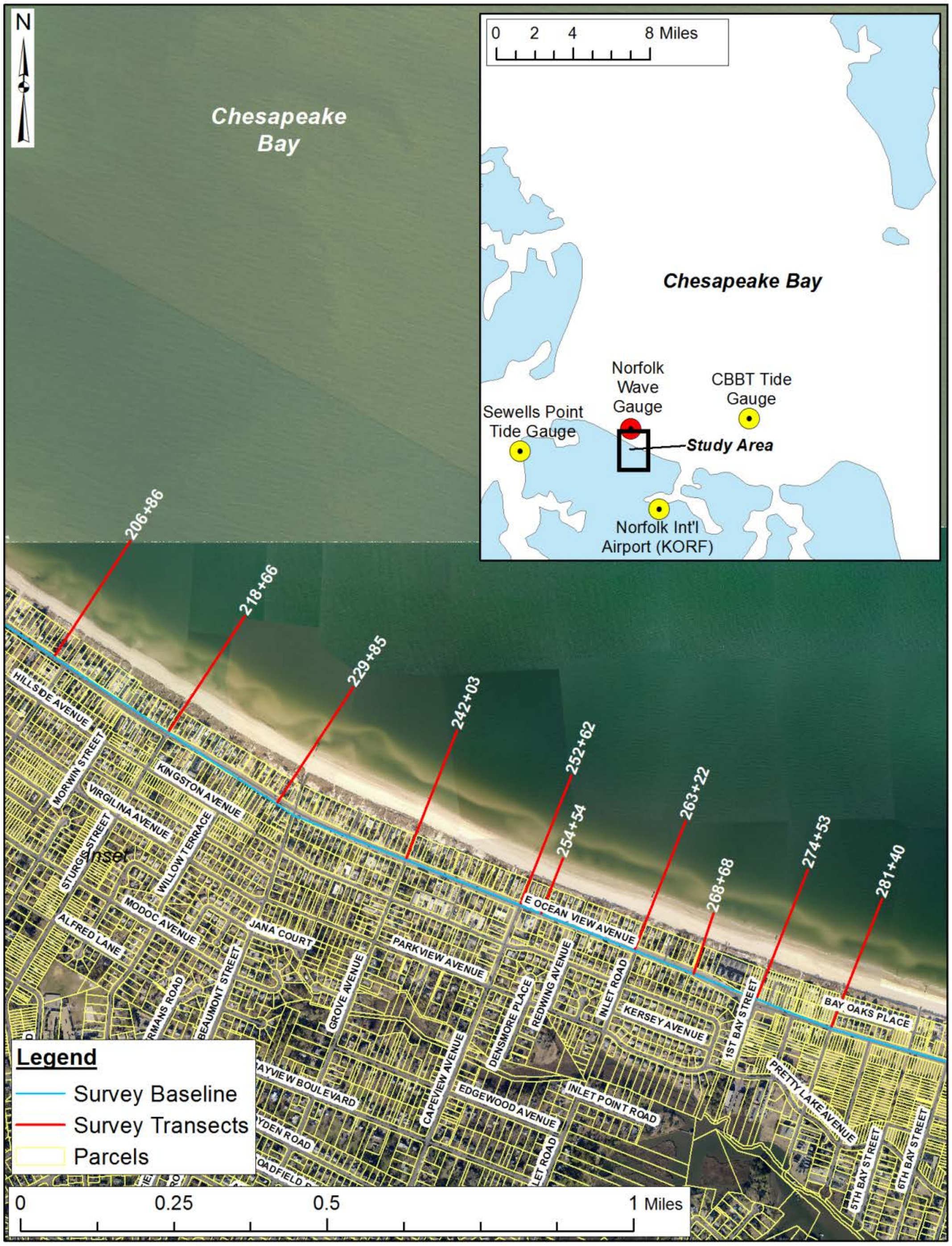

Figure 1: Location of Cottage Line dune integrity assessment site

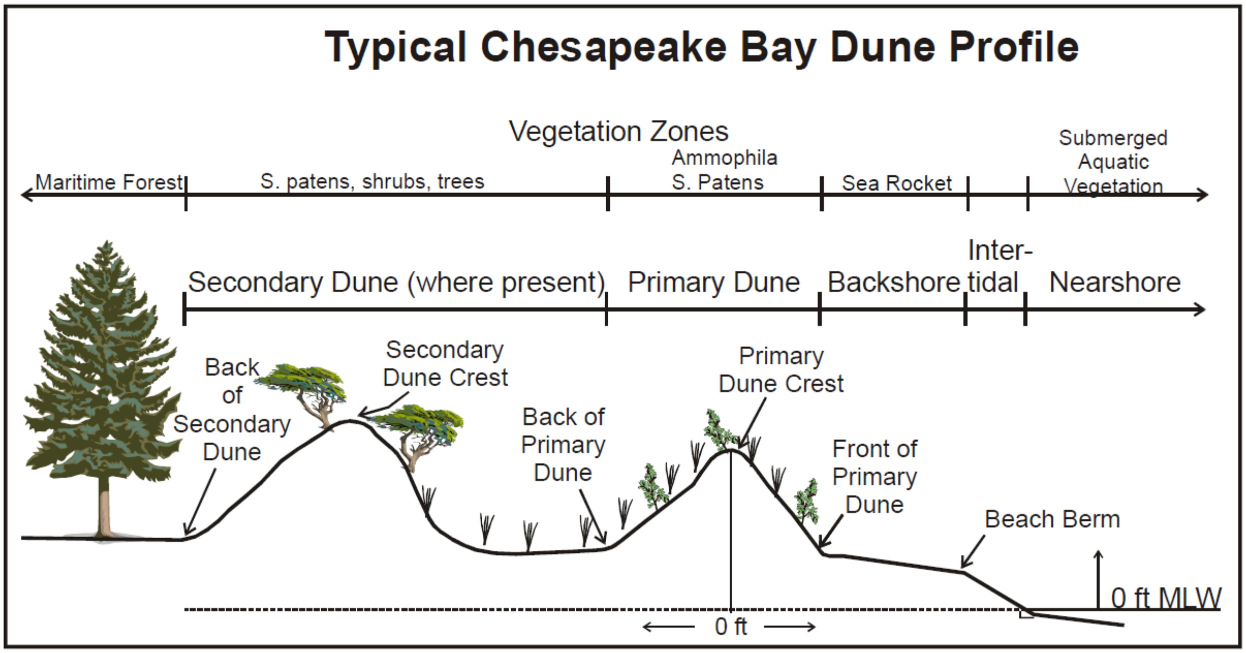

Figure 2: Typical elements of bay beach and dune (from Hardaway et al., 2001)

Vegetation is a natural and important component of the dune system. Dune grasses and shrubs, such as those noted on Figure 2, help to capture and stabilize sand deposited on the dune. However, the vegetation typically found on primary dunes generally does not provide significant erosion resistance during severe coastal storms, in which the intense wave action undercuts the dune face.

For reference, a similar sediment-stabilizing function is provided by living shorelines (grasses, shrub/scrub vegetation) and by mangroves (in more tropical areas) along shorelines less exposed to significant wave action.

Human actions also affect the width, height, total sand volume, and vegetation of the beach and dunes. Coastal communities, state and federal agencies, and private entities often place sand to build or restore beaches and dunes for increased storm protection. The City of Norfolk has invested significant City funds in beach nourishment, dune enhancement, and shoreline stabilization structures along the Ocean View and Willoughby Spit shorelines.

More than 20 property owners within and near the Cottage Line reach of Norfolk's Ocean View shoreline have expressed a desire to alter the present existing topographic conditions of the primary sand dunes along the shorelines of their individual properties. It is assumed that the dunes on adjacent properties would remain unaltered.

The City's Public Works, Planning, and Recreation Parks & Open Space Departments and the City's Wetlands Board are responsible for maintaining, managing, and regulating its beaches and dunes. The dunes along Cottage Line, and throughout Ocean View, provide varying degrees of flooding protection and erosion protection associated with coastal storms such as hurricanes, tropical storms, and nor'easters. As part of the process for considering applications by property owners to modify the dunes, the City needs to understand the impacts that such modifications would likely have on the capacity of the dunes to resist and mitigate coastal storm damage.

The City also has a responsibility to regulate actions in the flood zones designated by the Federal Emergency Management Agency (FEMA) in accordance with the requirements of participation in the National Flood Insurance Program (NFIP). These requirements are outlined in Title 44 of the Code of Federal Regulations. Among the many requirements of 44 CFR associated with the NFIP, Part 60.3(e)(7) states that the community (i.e. the City) must "prohibit man-made alterations of sand dunes and mangrove stands within Zones V1-30, VE, and V on the community's FIRM which would increase potential flood damage." The City's Flood Insurance Rate Map (FIRM) does identify such V zones (also known as coastal high hazard areas) along the Chesapeake Bay shoreline of Cottage Line, Ocean View, and Willoughby Spit.

The City has requested Moffatt & Nichol to provide technical services to assess the present capacity of the Cottage Line dunes to resist storm damage and to assess whether resident-proposed modifications to the dunes would increase potential coastal flood damage.

2. Approach

Figure 1 shows the Cottage Line study site with streets and City survey transects labeled. An inset map indicates the study area's position within the southern Chesapeake Bay. Coastal processes in the study area are influenced by diurnal astronomical tides, setup and set-down in tidal water levels ("surges") due to wind and atmospheric pressure effects, locally-generated wind waves, and waves propagating from the Atlantic Ocean.

The most severe elevated wind, wave, and surge conditions affecting Cottage Line are the result of tropical storms, hurricanes, and extratropical cyclonic storms (nor'easters). The high water levels associated with these storms allow severe storm-generated waves to impact the coastal system at higher elevations (i.e. further landward on the beach and dune), causing significant erosion and/or breaching of frontal dunes. The purpose of the project is to characterize the ability of the existing beach and dune system in Cottage Line to resist breaching by storm waves. The approach to the study is to apply a beach and dune profile change model to simulate the dune erosion likely to occur under a series of intense coastal storms.

The study is concerned primarily with the ability of the primary dunes along Cottage Line to protect structures and infrastructure from storm waves and surges. The measurable characteristic of the dune for judging its protective capacity is the dune's ability to resist breaching or severe overwash in combined high water levels and intense wave energy associated with hurricanes, tropical storms, and severe subtropical storms (nor'easters). This capacity is developed through both dune height (crest elevation) and dune width, which may also be expressed as the volume of sand existing in the dune above some elevation. This study utilizes the dune volume seaward of the seaward property line and above the elevation +8 feet NAVD88.

A "design storm" approach is taken in this study, in which representative historical storms are assumed to be indicative of the range of storm conditions that would be likely to impact the dune system. The approach taken is similar in concept to that taken by the USACE Norfolk District in its *Hurricane and Storm Damage Reduction Study for Hampton, Virginia* (USACE, 2002) and in its recent *Limited Reevaluation Report, Willoughby Spit and Vicinity, Norfolk, Virginia* (USACE, 2013). The primary differences are that the present study used a more limited number of design storms, because the aim of the present study is to assess the dune's ability to resist very severe storm wave and water level conditions. Multiple severe storms have occurred at the project site, including three storms – Tropical Storm Ernesto in October 2006, a nor'easter in November 2009 and Hurricane Irene in 2011 – that occurred recently enough that both water levels and waves were recorded by reliable instruments near the project site. Water levels were measured at Sewells Point for other storms included in this study – the August 1933 hurricane, the Ash Wednesday storm (nor'easter) in March 1962, and Hurricane Isabel in 2003. The available data allow the reasonable hindcasting of those storms' waves near the project site.

3. Storm Waves and Water Levels

Damage associated with coastal storms (such as hurricanes, tropical storms, nor'easters) typically comes from wind action, wave action, and/or storm surge. Dunes such as those found in Cottage Line do not provide significant wind damage mitigation, and wind damage is not considered further in this report. The dunes do provide meaningful protection from direct storm surge flooding and wave action. This chapter describes the storm surge and wave conditions used as input to model simulations and coastal engineering analyses focused on evaluating the degree of storm protection provided by the Cottage Line dunes.

When adjusted for historical sea level rise, the August 1933 hurricane remains the highest peak water level of any coastal storm affecting Norfolk since 1928; this storm's peak measured water level is equivalent to the 1% annual chance (100-year return period) water level from the effective Flood Insurance Study (FIS) for Norfolk (FEMA, 2009). FEMA uses the 1% annual chance coastal storm as the "Base Flood" for the FIS and Flood Insurance Rate Maps (FIRMs). However, it is well known that events more severe than the 1% annual chance do occur – as most recently demonstrated by Hurricane Sandy (2012). Therefore, for thoroughness in this dune integrity assessment, design storms more severe than the August 1933 hurricane were included; these storms are referred to herein as Hurricane X and Hurricane Y. Water levels for Hurricane X were developed by scaling the storm surge from the August 1933 hurricane to peak at the 0.5% annual chance (200-year return period) water level from the effective FIS (FEMA, 2009). Hurricane Y has a peak water level at the 90% confidence limit for the 0.5% annual chance water level from extreme value analysis on long-term data at Sewells Point. Waves for Hurricane X and Hurricane Y were equivalent to the August 1933 hurricane waves.

3.1. Water Levels

The most relevant long-term tide gage to this project site is NOAA #8638610 at Sewells Point, approximately 6 miles west of Cottage Line (Figure 1). Hourly measured water levels are available for this location since the original gage deployment in 1928. Water levels for the August 1933 hurricane were adjusted for sea level rise between 1933 and 2013 by adding 1.17 feet to the Sewells Point measured values, based on a sea level rise rate of 1.46 feet per 100 years (NOAA, 2014).

The seven design storms all have peak water levels above +5.0 feet NAVD88. For reference, the peak water levels for each storm, the FEMA September 2009 effective FIS stillwater levels and the USACE 2013 LRR stillwater levels for Norfolk, Virginia, are shown in Table 1.

When adjusted for sea level rise that has occurred since 1933, the historical hurricane of August 1933 – the highest water level in the entire Sewells Point tide gage record – is equivalent to the FEMA FIS 1% annual chance stillwater level. If relative sea level rise continues at the current rate without accelerating, all else remaining the same, water levels in Norfolk would increase by 0.44 feet in the next 30 years and by 0.73 feet in the next 50 years.

A primary implication of sea level rise is that storms with higher return periods today will be lower return period (more frequent) events in the future, due to the higher base tide levels to which the storm surge will be added. As an illustration, in 55 years the August 1933 hurricane's peak present-day water level of +7.4 feet NAVD88 would increase by 0.8 feet to +8.2 feet NAVD88, equivalent to Hurricane X. This means that a 200-year return period event today (Hurricane X) would become approximately a 100-year return period event in 55 years.

Table 1: Peak Water Levels for Storms and FEMA / USACE Stillwater Elevations

Description	**Water Level (feet NAVD88)[1]**	
	Measured at Sewells Point, adjusted for sea level rise	
Hurricane Y (0.5% annual chance)[2]	+9.1	
Hurricane X (0.5% annual chance)[2]	+8.2	
August 1933 hurricane	**+7.4**	
Ash Wednesday Storm (1962)	+6.4	
Hurricane Isabel (2003)	+6.3	
November 2009 nor'easter	+6.0	
Hurricane Irene (2011)	+5.9	
Tropical Storm Ernesto (2006)	+5.0	
	FEMA September 2009 FIS Stillwater Elevation Table	*USACE 2013 Limited Reevaluation Report*
500-year return period (0.2 % annual chance)	+8.9	+8.4
100-year return period (1 % annual chance)	**+7.6**	+7.1
50-year return period (2 % annual chance)	+6.9	+6.5
10-year return period (10 % annual chance)	+5.5	+5.2

[1]Measured water levels are adjusted for historical sea level rise up to year 2013. They do not include future sea level rise.

[2]Hurricanes X and Y are hypothetical design events, not observed historical events. Hurricane X peak water level is based on interpolation between the 1% and 0.2% annual chance stillwater elevations published in (FEMA 2009). Hurricane Y peak water level is based on 90% confidence interval extreme water levels analysis on historical, measured data at Sewells Point.

All of the historical storms (plus Hurricane X and Hurricane Y) listed in the upper part of Table 1 were simulated in the SBEACH models. Results are presented in detail in this report for four of those storms: the November 2009 nor'easter, the August 1933 hurricane, Hurricane X, and Hurricane Y. The Ash Wednesday Storm was a nor'easter with peak water levels greater than the peak water level in the November 2009 nor'easter. However, the Norfolk wave gage was not operational in 1962 during the Ash Wednesday Storm. Therefore, the November 2009 nor'easter is presented instead of the Ash Wednesday storm in order to evaluate a severe nor'easter for which measured wave and water level data are available from local measurement stations.

3.2. Wave Heights and Periods

SBEACH simulations are driven by the combined effects of storm waves acting on elevated storm water levels. At each calculation point along the profile, the model transforms the input wave heights and periods. Wave runup is also computed. The model computes additional elevation of input water levels due to the wave action (wave setup), and these adjusted wave and water level values are used in the profile change calculations. The model then computes the effects of the water levels and wave conditions on the beach and dune during the storm event, resulting in the expected final eroded profile. The wave and water level time series input to the SBEACH simulations for four severe design storms are shown in Figure 3 through Figure 6. Wave inputs for the November 2009 nor'easter were taken directly from measurements by the City's wave gage at Ocean View. Since the wave gage was not operational in 1933, wave inputs for the August 1933 hurricane were taken from the USACE engineering appendix to the Hampton, Virginia storm damage reduction feasibility study (USACE, 2002). Wave inputs for Hurricane X and Y are identical to those for the August 1933 hurricane.

The wave heights shown in the figures and used as input to SBEACH are significant wave heights at the location of the Norfolk wave gage, approximately 1.2 miles off of the shoreline near Warwick Avenue and Beach View Street. Because waves shoal and refract as they approach land, the wave heights over the beach are different than those measured at the Norfolk wave gage. The SBEACH model performs these wave height transformation calculations internally and applies the transformed wave heights to each position on the beach and dune profile.

Significant wave height (H_s) is defined as the average of the highest one-third of waves. The significant wave height is used by most coastal models as an indicator of the wave field. It is understood and accounted for in coastal models and methods – including SBEACH – that the largest waves in a given storm may be 70% to 80% higher than H_s, and these higher waves are those that pose the greatest wave runup risk.

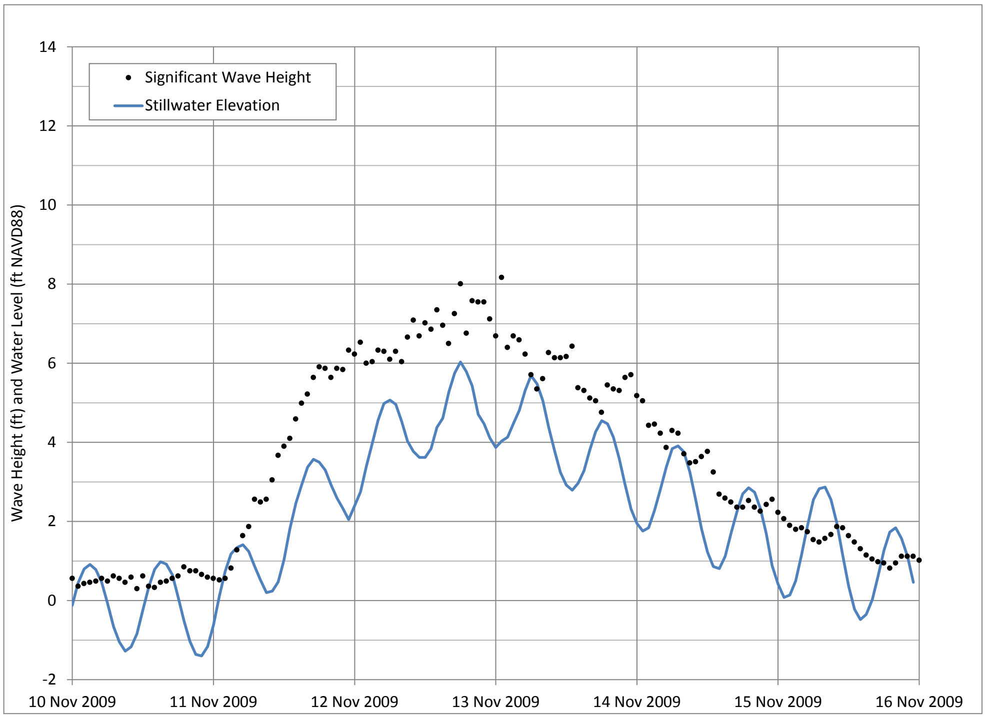

Figure 3: Measured significant wave heights at Norfolk wave gage and water levels at Sewells Point, 2009 nor'easter

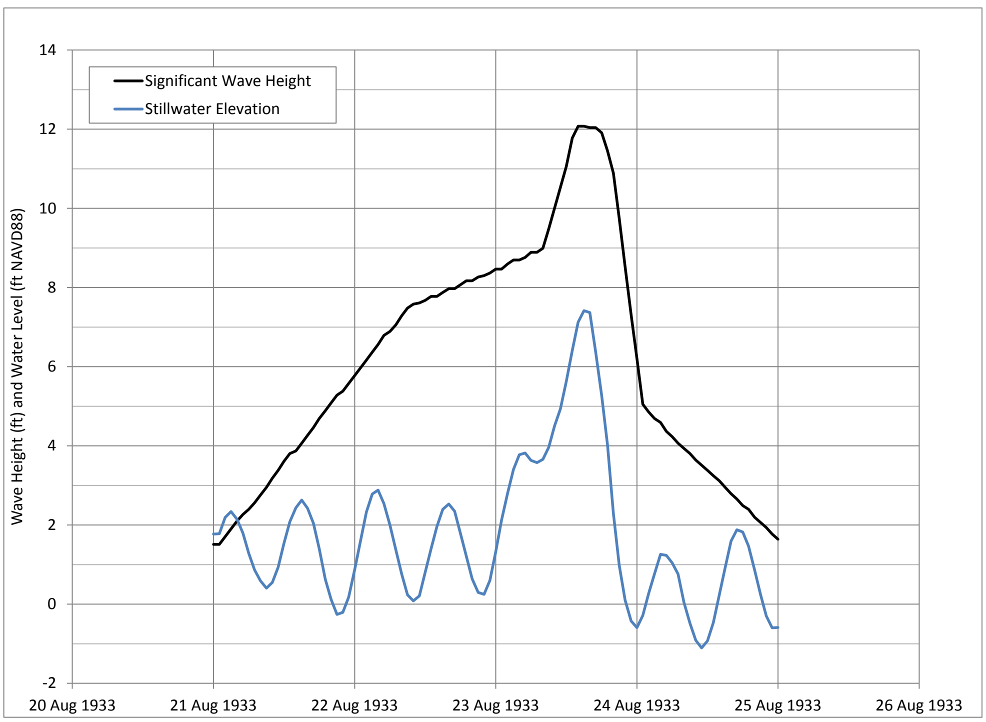

Figure 4: Model significant wave heights in Chesapeake Bay and measured water levels at Sewells Point, August 1933 hurricane

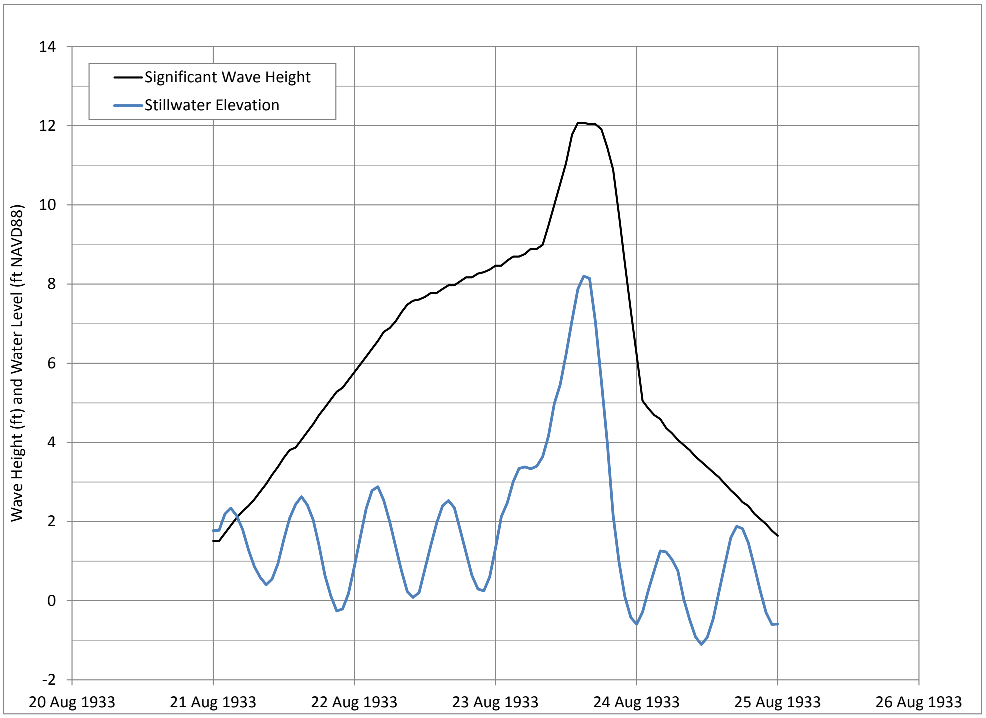

Figure 5: Estimated significant wave heights at Norfolk wave gage and water levels at Sewells Point, Hurricane X

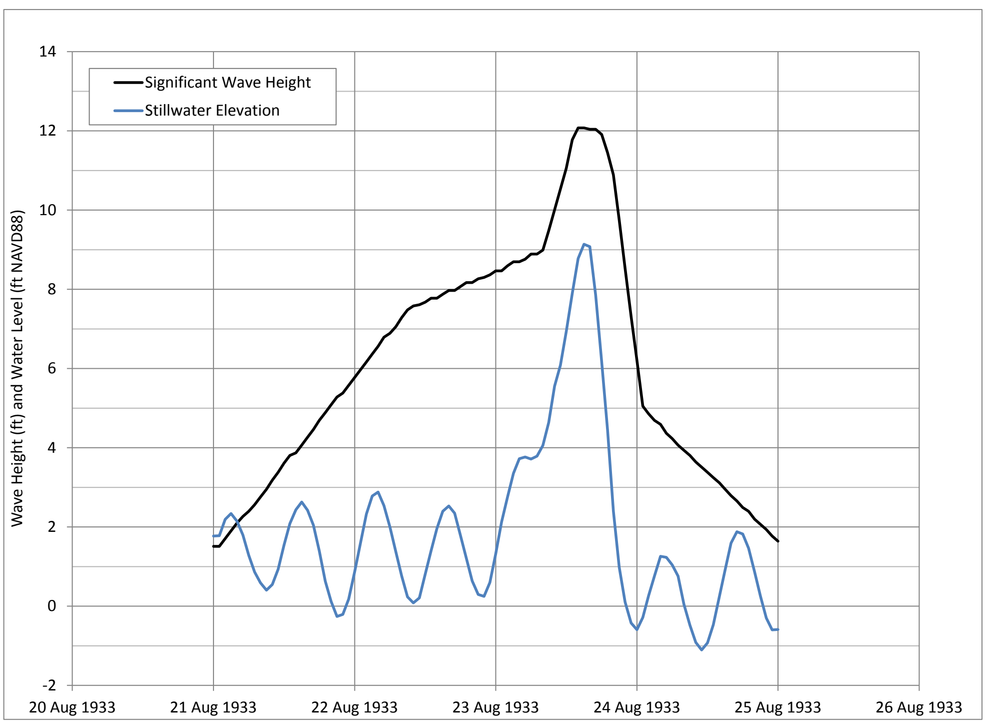

Figure 6: Estimated significant wave heights at Norfolk wave gage and water levels at Sewells Point, Hurricane Y

4. Beach Profile Change Modeling

4.1. Introduction

The central focus of this study is the assessment of the integrity of the Cottage Line dune system – i.e. the dune's ability to resist breaching and severe overwash – during extreme storm events. Dune integrity was assessed using results from beach profile change simulations in the SBEACH computational model. SBEACH is a two-dimensional (elevation [z] and cross-shore distance [x]) model developed by USACE for simulating beach and dune profile change in storm wave and water level conditions. The model is described in detail in the various USACE technical references (Larson, et al., 1989, 1990, 1998, 2004; Rosati, et al., 1993); these references and others are available from the USACE Coastal & Hydraulic Laboratory website: http://chl.erdc.usace.army.mil/chl.aspx?p=s&a=Publications;118&g=92.

SBEACH capabilities include the simulation of dune erosion and redistribution of sediments lower in the profile. SBEACH is also capable of simulating wave setup (water level increase at the dune due to wave action), which raises the elevation of wave attack and increases the chance of the dune being overwashed or breached in a storm event.

All of the SBEACH simulations were conducted with initial profiles from the most recent available nearshore, beach, and dune survey profile elevation data. Elevation data utilized in the present study include a field topographic / hydrographic survey along Ocean View beaches completed October 16 – 18, 2013 by Geodynamics, LLC (as a subconsultant to Moffatt & Nichol). City of Norfolk staff surveyors provided data from a January 2014 survey at two transects additional to the regular monitoring transects. Beach profile charts at all 9 transects are included in Appendix A: Existing Condition Beach and Dune Profiles. Note that the vertical scale is exaggerated on the charts, and the profile locations correspond to the numbered transect lines in Figure 1.

The post-storm beach and dune profiles resulting from the SBEACH simulations were inspected and coastal engineering judgment applied to develop conclusions regarding dune integrity for existing conditions and for representative modified dune scenarios.

4.2. Sediment Characteristics

The SBEACH model requires inputs regarding the characteristics of the beach and dune sediments. Historical surface sediment sampling and laboratory gradation testing indicated that a median grain size of D_{50} = 0.40 mm is representative of the sand comprising the beach and dune along the Ocean View shoreline. A maximum allowable slope angle before avalanching of 35 degrees was used as a typical value for medium sand.

4.3. Existing Conditions Dune Erosion Potential

SBEACH simulations, for the three intense storms evaluated, indicated that the existing condition dunes would perform as indicated in Table 2. In the table, the primary dune crest elevation is rounded to the nearest foot; dune volume is calculated as the volume per linear foot above elevation +8 ft NAVD88 and seaward of the seaward edge of the property parcel line. Parcel boundaries were taken from the City of Norfolk GIS parcel shapefiles.

Figure 7 illustrates the area used for dune volume calculation and the seaward parcel line. Virginia coastal policy generally defines the coastal primary sand dune as a "mound of unconsolidated sandy soil which is contiguous to mean high water, whose landward and lateral limits are marked by a change in grade from 10% or greater to less than 10%," with additional provisions for vegetation (refer to 4 VAC 20-440-10 Barrier Island Policy). The dune volume relevant to this engineering study and report is a subset of the total volume of the primary dune. Several of the most widely-utilized methods for predicting dune erosion in coastal storms (e.g. FEMA, 2003) consider that the landward retreat of the dune and the reduction in crest height and volume are related to the pre-storm volume of sand in a "reservoir" above the storm's stillwater elevation. The +8 ft NAVD88 elevation is used for discussing the dune volume relevant to dune erosion in Cottage Line, to represent the average stillwater level between the 1% annual chance and the 0.5% annual chance hurricane events.

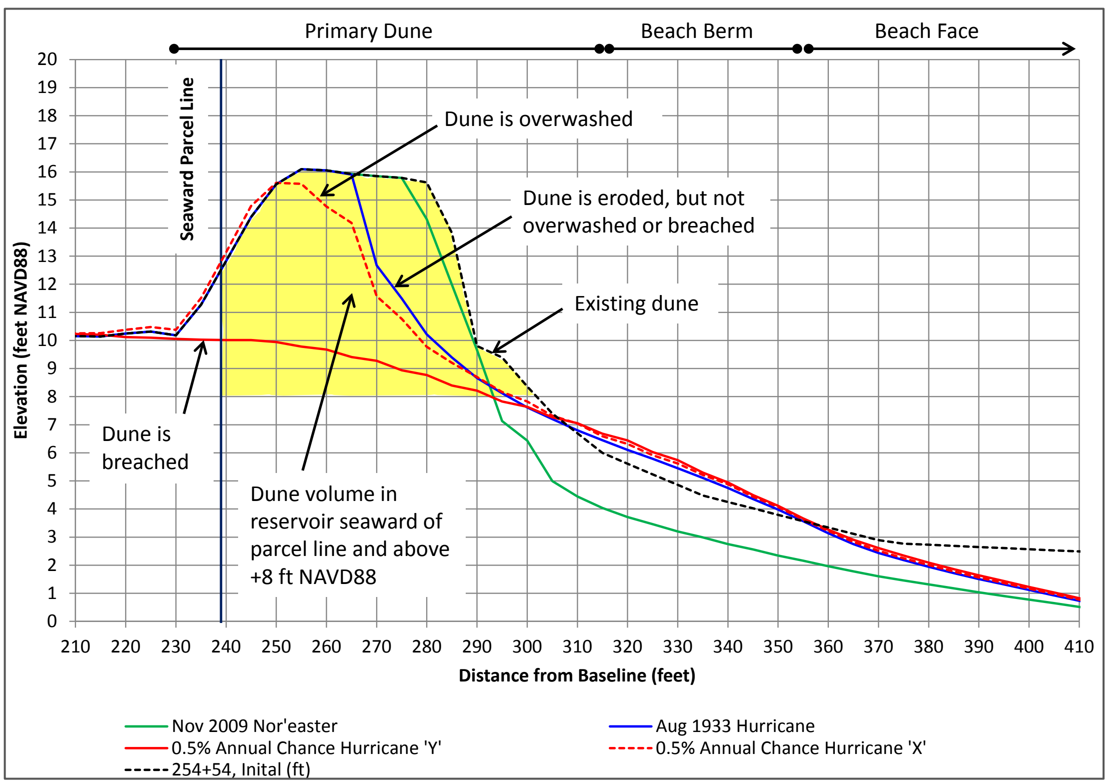

Figure 7: Illustration of dune volume definition and dune erosion classifications

Figure 7 also shows the difference between dune erosion, overwash, and breaching. A dune eroded by a nor'easter or hurricane may still retain sufficient volume to provide flood protection. Overwash occurs when a dune is eroded to the point that waves can flow over the dune crest, accelerating erosion damage and potentially exposing landward areas to flooding from overtopping water. When a dune is breached by a storm, most or all of its capacity to protect landward areas from flooding by storm surge and/or wave runup is eliminated.

Table 2: SBEACH Model Dune Erosion – Existing Conditions

Transect Location	Existing Primary Dune Crest Elevation, Volume[1]	November 2009 Nor'easter	August 1933 Hurricane	Hurricane X (0.5% a.c.)	Hurricane Y (0.5% a.c.)
206+86 Beach View St.	+14 ft NAVD88 12 cy/LF	Eroded	Breached	Breached	Breached
218+66 Sturgis St.	+16 ft NAVD88 21 cy/LF	Eroded	Eroded	Heavily overwashed	Breached
229+85 Beaumont St.	+19 ft NAVD88 25 cy/LF	Eroded	Eroded	Eroded	Eroded
242+03 Grove Ave.	+20 ft NAVD88 32 cy/LF	Eroded	Eroded	Eroded	Eroded
254+54 E. of Cape View	+16 ft NAVD88 14 cy/LF	Eroded	Eroded	Overwashed	Breached
263+22 Inlet Rd.	+21 ft NAVD88 20 cy/LF	Eroded	Eroded	Eroded	Eroded
268+68 Between Inlet Rd. and 1st Bay St.	+22 ft NAVD88 30 cy/LF	Eroded	Eroded	Eroded	Eroded
274+53 1st Bay St.	+18 ft NAVD88 25 cy/LF	Eroded	Eroded	Eroded	Eroded
281+40 3rd Bay St.	+20 ft NAVD88 25 cy/LF	Eroded	Eroded	Eroded	Heavily overwashed

[1]Unless otherwise indicated on the individual figures, dune profile charts presented in this report include gridlines such that each grid box is equivalent to a volume of 10 square feet per linear foot which is approximately 0.37 cy/LF.

SBEACH model results for each of the three storms in Table 2, for existing conditions, are provided in Appendix B. As one would expect, transects with lower dune crest elevations and/or lower volumes of sediment in the upper dune suffered more erosion than transects with both higher crests and greater volumes. In the 2009 nor'easter simulation, the dunes' front faces were eroded and the dune at 3rd Bay Street was slightly overwashed by waves (Figure 8); no significant coastal flood or wave action at the property lines was indicated at any location. In the August 1933 hurricane simulation, greater dune face and crest erosion resulted at all transects. Overwash was again indicated at 3rd Bay Street; the dune at Beach View Street was breached, allowing wave runup to penetrate to the property line (see Figure 9).

Dunes at two of the nine transects were breached or heavily overwashed in the Hurricane X simulation in such as a way that wave impacts would occur at the seaward parcel lines. Four of the nine transects showed breaching or overwash in the Hurricane Y simulation. At transect 254+54 East of Cape View Avenue (Figure 10), Hurricane Y would completely remove the primary dune and cause erosion within the parcel boundaries.

In general, the existing dunes at Cottage Line offer substantial protection from coastal storm surges and waves during the hurricanes and nor'easters that have historically impacted Ocean View. Potential weak points in the dune line exist for storms more intense than the August 1933 hurricane, as indicated by breaching and heavy overwash in the 0.5% annual chance (200-year return period) Hurricane X and Hurricane Y storms simulated in this study. SBEACH model results for each of the four storms in Table 2, for existing conditions, are provided in Appendix B. However, it should be noted that the results are based on current sea levels. If sea level continues to rise at current or accelerated rates, within a few decades the erosion in the above storms will be more severe and potential flooding risk will increase.

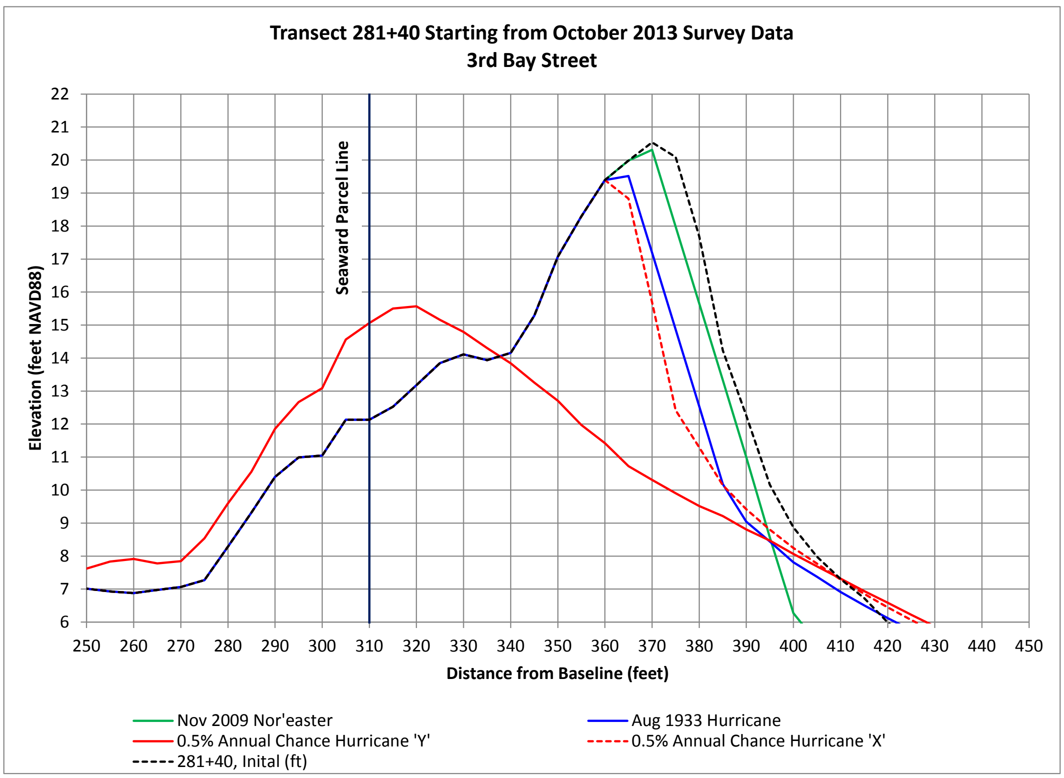

Figure 8: SBEACH results at 3rd Bay St. for existing dune

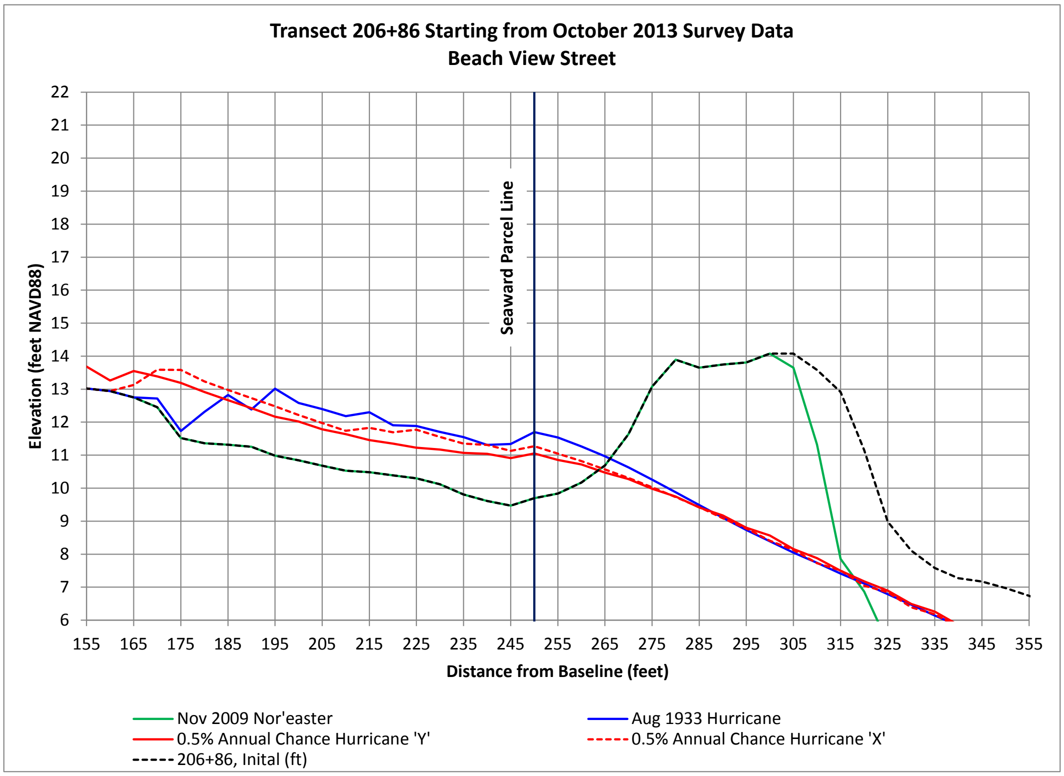

Figure 9: SBEACH results at Beach View St. for existing dune

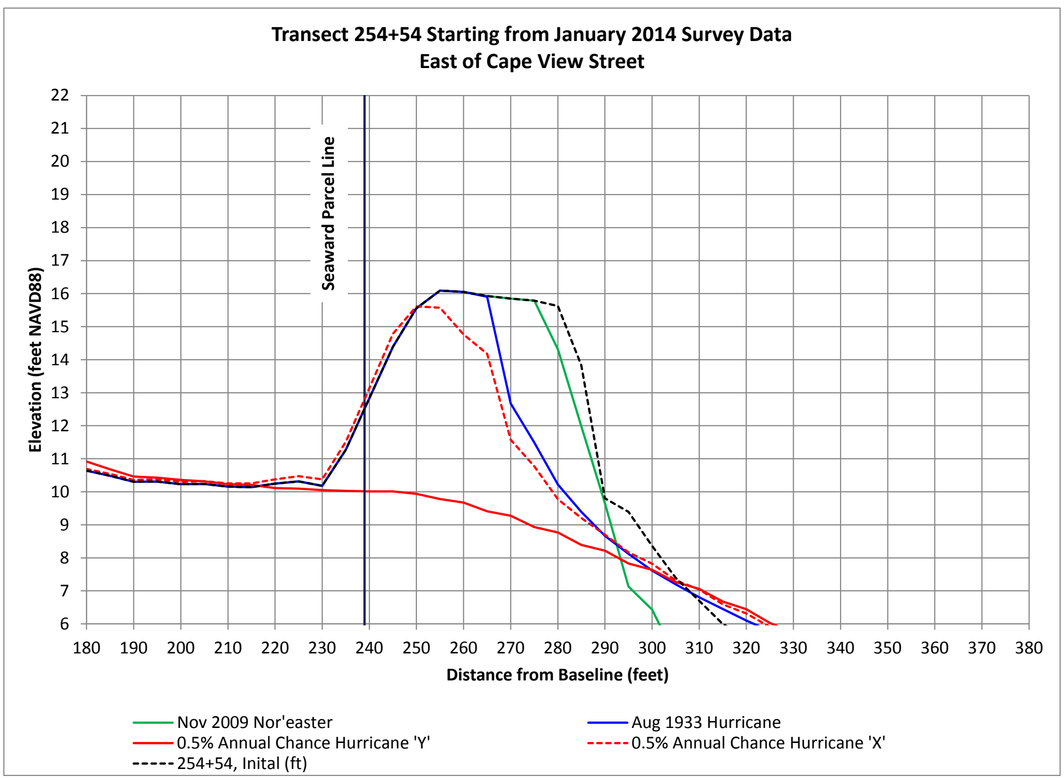

Figure 10: SBEACH results east of Cape View Ave. for existing dune

In its coastal flood hazard mapping FIRM production, FEMA uses a frontal dune reservoir volume of 540 square feet per linear foot (ft^2/LF) as a threshold for determining whether the dune will be removed during the 1% annual chance (100-year return period) coastal flood event. This is at times referred to as the FEMA 540 Rule. The frontal dune reservoir is defined as the dune volume above the 1% annual chance stillwater elevation (+7.6 ft NAVD88 in Ocean View, rounded to +8 ft NAVD88) and seaward of the peak / rear shoulder of the dune. In general, if the frontal dune reservoir volume is less than 540 ft^2/LF (or, 20 cy/LF) the dune is considered to be removed during the 1% annual chance coastal flood event. If the frontal dune reservoir volume is greater than 540 ft^2/LF the dune will be eroded and will retreat. The detailed methodology for calculating the frontal dune reservoir volume and for determining dune removal and retreat profiles for Flood Insurance Studies is outlined in Appendix D of FEMA's Guidelines and Specifications for Flood Hazard Mapping Partners (FEMA, 2003).

Frontal dune reservoir volumes were calculated for the existing conditions Cottage Line dune profiles, and the values are presented in Table 3. Five of the nine transects have frontal dune reservoir volumes less than 540 ft^2/LF; these are highlighted by yellow shading in the table.

Table 3: Existing Dune Volume Above +8 ft NAVD88 and Within Frontal Dune Reservoir

Transect Location	Existing Primary Dune Crest Elevation and Volume[1] Above +8 ft NAVD88	Interpreted Frontal Dune Reservoir Volume[2] Above +8ft NAVD88
206+86 Beach View St.	+14 ft NAVD88 12 cy/LF	365 ft^2/LF 13.5 cy/LF
218+66 Sturgis St.	+16 ft NAVD88 21 cy/LF	462 ft^2/LF 17.1 cy/LF
229+85 Beaumont St.	+19 ft NAVD88 25 cy/LF	532 ft^2/LF 19.7 cy/LF
242+03 Grove Ave.	+20 ft NAVD88 32 cy/LF	629 ft^2/LF 23.3 cy/LF
254+54 E. of Cape View	+16 ft NAVD88 14 cy/LF	329 ft^2/LF 12.2 cy/LF
263+22 Inlet Rd.	+21 ft NAVD88 20 cy/LF	505 ft^2/LF 18.7 cy/LF
268+68 Between Inlet Rd. and 1st Bay St.	+22 ft NAVD88 30 cy/LF	780 ft^2/LF 28.9 cy/LF
274+53 1st Bay St.	+18 ft NAVD88 25 cy/LF	705 ft^2/LF 26.1 cy/LF
281+40 3rd Bay St.	+20 ft NAVD88 25 cy/LF	626 ft^2/LF 23.2 cy/LF

[1]Recall this volume is calculated above +8 ft NAVD88 and seaward of the seaward edge of the property parcel as contained in the City GIS parcel shapefile.

[2]Calculated using guidance from Section D.2 in (FEMA, 2003). Compare values to FEMA 540 ft^2/LF threshold.

Recall from Table 2 that the existing conditions SBEACH models indicated breaching in the 0.5% annual chance Hurricane Y storm at the three transects with the lowest frontal dune reservoir volumes –Beach View Street, Sturgis Street, and East of Cape View Street. Only one of the transects (Beach View Street) was breached in the August 1933 hurricane, approximating a 1% annual chance coastal storm. It is noted that the 540 Rule was developed by FEMA as a simplified method of artificially eroding the primary frontal dune in preparation for determining coastal high hazard zones ("VE" zones) through local wave transformation calculations. FEMA requires a simplified method in order to efficiently and consistently determine and map coastal flood hazard zones across the entire open Atlantic Ocean and Gulf of Mexico coastline. The approach used in the present study – applying the SBEACH model to simulate beach profile change directly in response to ***location-specific*** design storm time series of waves and water levels – is more applicable to the purposes of the present study.

4.4. Impact of Dune Modifications

Dune erosion simulations were run for a series of dune modifications, in order to evaluate the impacts on the capacity of lower crest and lower volume dunes to provide storm damage mitigation. In each of six SBEACH simulation sets, the existing dune crest elevation was cut off down to a lower level, starting at +18 ft NAVD88 and proceeding through simulation of a +12 ft NAVD88 dune crest. SBEACH model results for each of the lowered dune crest elevation sets are provided in Appendices C through H.

As the dune crest elevation was lowered in each simulation, the volume of sand reservoir available to resist wave action was decreased. Predicted dune erosion increased progressively as this combination of dune height and dune volume decreased. This study is primarily concerned with evaluating the ***potential increase in coastal storm damage potential*** associated with ranges of dune height and/or volume reduction. For the purposes of this discussion, the increases in potential for damage from coastal flooding, wave action, and/or erosion at the parcel boundaries are classified as follows, in order of increasing severity:

- No Increase in Flood Damage (NIFD) – Erosion of the dune indicated by SBEACH may be greater than for existing conditions, but the dune was not overwashed and the dune crest level was not significantly reduced.
- Increased Damage from Flooding or Waves (IDFW) – Dune remains but is very likely to be overwashed or breached in the identified storm event, and the landward areas are likely to be exposed to storm wave runup and flooding.
- Increased Damage plus Erosion or Undermining (**IDEU**) – The dune was completely overwashed / breached and reduced to a very flat slope that provides virtually no ability to block storm wave runup and flooding.

Table 4 summarizes the dune reservoir volumes and the damage potential indicated for the November 2009 nor'easter storm SBEACH simulations. Each column indicates the associated modified (lowered) dune crest elevation. Where "n/a" is given, the existing dune crest elevations were already lower than the column heading dune crest elevation, and the results are equivalent to the existing condition results. Table 5, Table 6 and Table 7 provide similar information for the August 1933 hurricane, Hurricane X, and Hurricane Y, respectively.

Table 4: SBEACH Model Dune Erosion – Modified Dune in 2009 Nor'easter

Transect Location	Existing Crest Elevation and Volume	Crest at +18 ft NAVD88	Crest at +17 ft NAVD88	Crest at +16 ft NAVD88	Crest at +15 ft NAVD88	Crest at +14 ft NAVD88	Crest at +12 ft NAVD88
206+86 Beach View St.	+14 ft 12 cy/LF	n/a	n/a	n/a	n/a	NIFD 12 cy/LF	NIFD 10 cy/LF
218+66 Sturgis St.	+16 ft 21 cy/LF	n/a	n/a	NIFD 21 cy/LF	NIFD 21 cy/LF	NIFD 20 cy/LF	NIFD 17 cy/LF
229+85 Beaumont St.	+19 ft 25 cy/LF	NIFD 25 cy/LF	NIFD 24 cy/LF	NIFD 23 cy/LF	NIFD 21 cy/LF	NIFD 19 cy/LF	NIFD 15 cy/LF
242+03 Grove Ave.	+20 ft 32 cy/LF	NIFD 30 cy/LF	NIFD 29 cy/LF	NIFD 27 cy/LF	NIFD 25 cy/LF	NIFD 23 cy/LF	NIFD 17 cy/LF
254+54 E. of Cape View	+16 ft 14 cy/LF	n/a	n/a	NIFD 14 cy/LF	NIFD 13 cy/LF	NIFD 11 cy/LF	NIFD 8 cy/LF
263+22 Inlet Rd.	+21 ft 20 cy/LF	NFID 18 cy/LF	NFID 18 cy/LF	NIFD 17 cy/LF	NIFD 16 cy/LF	NIFD 15 cy/LF	NIFD 12 cy/LF
268+68 Between Inlet Rd. and 1st Bay St.	+22 ft 30 cy/LF	NIFD 24 cy/LF	NIFD 22 cy/LF	NIFD 20 cy/LF	NIFD 18 cy/LF	NIFD 16 cy/LF	NIFD 11 cy/LF
274+53 1st Bay St.	+18 ft 25 cy/LF	NIFD 25 cy/LF	NIFD 25 cy/LF	NIFD 24 cy/LF	NIFD 22 cy/LF	NIFD 20 cy/LF	NIFD 14 cy/LF
281+40 3rd Bay St.	+20 ft 25 cy/LF	NIFD 23 cy/LF	NIFD 22 cy/LF	NIFD 21 cy/LF	NIFD 20 cy/LF	NIFD 18 cy/LF	NIFD 13 cy/LF

Table 5: SBEACH Model Dune Erosion – Modified Dune in 1933 August Hurricane

Transect Location	Existing Crest Elevation and Volume	Crest at +18 ft NAVD88	Crest at +17 ft NAVD88	Crest at +16 ft NAVD88	Crest at +15 ft NAVD88	Crest at +14 ft NAVD88	Crest at +12 ft NAVD88
206+86 Beach View St.	+14 ft 12 cy/LF	n/a	n/a	n/a	n/a	IDFW 12 cy/LF	IDFW 10 cy/LF
218+66 Sturgis St.	+16 ft 21 cy/LF	n/a	n/a	NIFD 21 cy/LF	NIFD 21 cy/LF	IDFW 20 cy/LF	IDFW 17 cy/LF
229+85 Beaumont St.	+19 ft 25 cy/LF	NIFD 25 cy/LF	NIFD 24 cy/LF	NIFD 23 cy/LF	NIFD 21 cy/LF	NIFD 19 cy/LF	IDFW 15 cy/LF
242+03 Grove Ave.	+20 ft 32 cy/LF	NIFD 30 cy/LF	NIFD 29 cy/LF	NIFD 27 cy/LF	NIFD 25 cy/LF	IDFW 23 cy/LF	IDFW 17 cy/LF
254+54 E. of Cape View	+16 ft 14 cy/LF	n/a	n/a	NIFD 14 cy/LF	NIFD 13 cy/LF	IDFW 11 cy/LF	**IDEU** 8 cy/LF
263+22 Inlet Rd.	+21 ft 20 cy/LF	NFID 18 cy/LF	NFID 18 cy/LF	NIFD 17 cy/LF	NIFD 16 cy/LF	NIFD 15 cy/LF	NIFD 12 cy/LF
268+68 Between Inlet Rd. and 1st Bay St.	+22 ft 30 cy/LF	NIFD 24 cy/LF	NIFD 22 cy/LF	IDFW 20 cy/LF	IDFW 18 cy/LF	IDFW 16 cy/LF	IDFW 11 cy/LF
274+53 1st Bay St.	+18 ft 25 cy/LF	NIFD 25 cy/LF	NIFD 25 cy/LF	NIFD 24 cy/LF	NIFD 22 cy/LF	IDFW 20 cy/LF	IDFW 14 cy/LF
281+40 3rd Bay St.	+20 ft 25 cy/LF	NIFD 23 cy/LF	NIFD 22 cy/LF	NIFD 21 cy/LF	IDFW 20 cy/LF	IDFW 18 cy/LF	IDFW 13 cy/LF

Table 6: SBEACH Model Dune Erosion – Modified Dune in Hurricane X (0.5% Annual Chance)

Transect Location	Existing Crest Elevation and Volume	Crest at +18 ft NAVD88	Crest at +17 ft NAVD88	Crest at +16 ft NAVD88	Crest at +15 ft NAVD88	Crest at +14 ft NAVD88	Crest at +12 ft NAVD88
206+86 Beach View St.	+14 ft 12 cy/LF	n/a	n/a	n/a	n/a	IDFW 12 cy/LF	IDFW 10 cy/LF
218+66 Sturgis St.	+16 ft 21 cy/LF	n/a	n/a	IDFW 21 cy/LF	IDFW 21 cy/LF	IDFW 20 cy/LF	IDFW 17 cy/LF
229+85 Beaumont St.	+19 ft 25 cy/LF	NIFD 25 cy/LF	NIFD 24 cy/LF	NIFD 23 cy/LF	NIFD 21 cy/LF	IDFW 19 cy/LF	IDFW 15 cy/LF
242+03 Grove Ave.	+20 ft 32 cy/LF	NIFD 30 cy/LF	NFID 29 cy/LF	NIFD 27 cy/LF	IDFW 25 cy/LF	IDFW 23 cy/LF	IDFW 17 cy/LF
254+54 E. of Cape View	+16 ft 14 cy/LF	n/a	n/a	IDFW 14 cy/LF	**IDEU** 13 cy/LF	**IDEU** 11 cy/LF	**IDEU** 8 cy/LF
263+22 Inlet Rd.	+21 ft 20 cy/LF	NIFD 18 cy/LF	NIFD 18 cy/LF	NIFD 17 cy/LF	NIFD 16 cy/LF	NIFD 15 cy/LF	NIFD 12 cy/LF
268+68 Between Inlet Rd. and 1st Bay St.	+22 ft 30 cy/LF	NIFD 24 cy/LF	IDFW 22 cy/LF	IDFW 20 cy/LF	**IDEU** 18 cy/LF	**IDEU** 16 cy/LF	**IDEU** 11 cy/LF
274+53 1st Bay St.	+18 ft 25 cy/LF	NIFD 25 cy/LF	NIFD 25 cy/LF	IDFW 24 cy/LF	IDFW 22 cy/LF	IDFW 20 cy/LF	**IDEU** 14 cy/LF
281+40 3rd Bay St.	+20 ft 25 cy/LF	NIFD 23 cy/LF	IDFW 22 cy/LF	IDFW 21 cy/LF	IDFW 20 cy/LF	IDFW 18 cy/LF	**IDEU** 13 cy/LF

Table 7: SBEACH Model Dune Erosion – Modified Dune in Hurricane Y (0.5% Annual Chance)

Transect Location	Existing Crest Elevation and Volume	Crest at +18 ft NAVD88	Crest at +17 ft NAVD88	Crest at +16 ft NAVD88	Crest at +15 ft NAVD88	Crest at +14 ft NAVD88	Crest at +12 ft NAVD88
206+86 Beach View St.	+14 ft 12 cy/LF	n/a	n/a	n/a	n/a	IDFW 12 cy/LF	IDFW 10 cy/LF
218+66 Sturgis St.	+16 ft 21 cy/LF	n/a	n/a	IDFW 21 cy/LF	IDFW 21 cy/LF	IDFW 20 cy/LF	**IDEU** 17 cy/LF
229+85 Beaumont St.	+19 ft 25 cy/LF	NIFD 25 cy/LF	IDFW 24 cy/LF	IDFW 23 cy/LF	IDFW 21 cy/LF	IDFW 19 cy/LF	IDFW 15 cy/LF
242+03 Grove Ave.	+20 ft 32 cy/LF	NIFD 30 cy/LF	IDFW 29 cy/LF	IDFW 27 cy/LF	IDFW 25 cy/LF	IDFW 23 cy/LF	**IDEU** 17 cy/LF
254+54 E. of Cape View	+16 ft 14 cy/LF	n/a	n/a	**IDEU** 14 cy/LF	**IDEU** 13 cy/LF	**IDEU** 11 cy/LF	**IDEU** 8 cy/LF
263+22 Inlet Rd.	+21 ft 20 cy/LF	IDFW 18 cy/LF	**IDEU** 18 cy/LF	**IDEU** 17 cy/LF	**IDEU** 16 cy/LF	**IDEU** 15 cy/LF	**IDEU** 12 cy/LF
268+68 Between Inlet Rd. and 1st Bay St.	+22 ft 30 cy/LF	IDFW 24 cy/LF	IDFW 22 cy/LF	**IDEU** 20 cy/LF	**IDEU** 18 cy/LF	**IDEU** 16 cy/LF	**IDEU** 11 cy/LF
274+53 1st Bay St.	+18 ft 25 cy/LF	NIFD 25 cy/LF	IDFW 25 cy/LF	IDFW 24 cy/LF	IDFW 22 cy/LF	**IDEU** 20 cy/LF	**IDEU** 14 cy/LF
281+40 3rd Bay St.	+20 ft 25 cy/LF	IDFW 23 cy/LF	**IDEU** 22 cy/LF	**IDEU** 21 cy/LF	**IDEU** 20 cy/LF	**IDEU** 18 cy/LF	**IDEU** 13 cy/LF

While dune erosion increased over existing conditions at some transects in the November 2009 nor'easter, the SBEACH simulations did not indicate an increase in coastal flood damage potential for that storm.

In the August 1933 hurricane simulations (Table 5), increases in damage potential were indicated at two transects with a dune crest elevation of +15 ft NAVD88; damage potential increases were indicated at eight of the nine transects with crest elevations of +14 ft NAVD88 and lower. Based on these results, a minimum dune elevation of +16 ft NAVD88 <u>and</u> a minimum dune volume of 23 cy/LF are needed to consistently provide protection in the August 1933 hurricane.

In the Hurricane X simulation (Table 6), increase in damage potential was indicated at 3rd Bay Street and at transect 268+68 between Inlet Road and 1st Bay Street with a dune crest elevation of +17 ft NAVD88. Five of the nine transects showed increased damage potential with a crest elevation of +16 ft NAVD88. A minimum dune elevation of +17 ft NAVD88 <u>and</u> a minimum dune volume of 25 cy/LF are needed to provide protection in a storm equivalent to Hurricane X.

The difference in damage potential between the August 1933 hurricane and the 0.5% annual chance Hurricane Y simulations is dramatic (Table 7). Reducing the dune crest elevation to +18 ft NAVD88 resulted in increased potential for wave runup flooding at Inlet Road, at 3rd Bay Street, and at transect 268+68 between Inlet Road and 1st Bay Street. Reducing existing dunes to a +17 ft NAVD88 crest elevation resulted in wave and/or erosion damage at all remaining transects. A minimum dune elevation of +18 ft NAVD88 <u>and</u> a minimum dune volume of 29 cy/LF are needed to provide protection in a storm equivalent to Hurricane Y.

Transect 268+68 between Inlet Road and 1st Bay Street is unlike any other location in the Cottage Line study area. At this location on a presently vacant lot (see Appendix A, page A-7), the first dune peak crests at approximately +22 ft NAVD88 and is thus at a similar elevation and in a similar line to the primary dune at adjacent transects. However, the sand does not slope down significantly behind this first dune peak. Rather, within approximately 30 feet landward of the first dune peak, a very high-crested and high-volume dune begins and peaks at +31 ft NAVD88. The SBEACH results shown in Figure 11 indicate that a dune crest elevation of +12 ft NAVD88 would result in overwash and wave runup flooding in the August 1933 hurricane, Hurricane X, and Hurricane Y. Lowering the dune to +17 ft NAVD88 (Figure 12) would increase flood risk between the seaward parcel line and the line of adjacent structures.

An additional caution is given regarding transect 268+68: Before any modifications are permitted to the dune crest height or volume, it will be important to confirm whether the landward penetration of wave runup would adversely affect adjacent properties to the left or right along the dune line (Figure 13). For example, wave runup penetrating to the seaward parcel line (as indicated in Figure 11 and Figure 12) may flow laterally behind the primary dune line on the eastern adjacent parcel. A similar situation could occur for dune modifications a few parcels to the west of transect 268+68. Specific proposed modification scenarios should be checked by a qualified coastal engineer, if such an application is made.

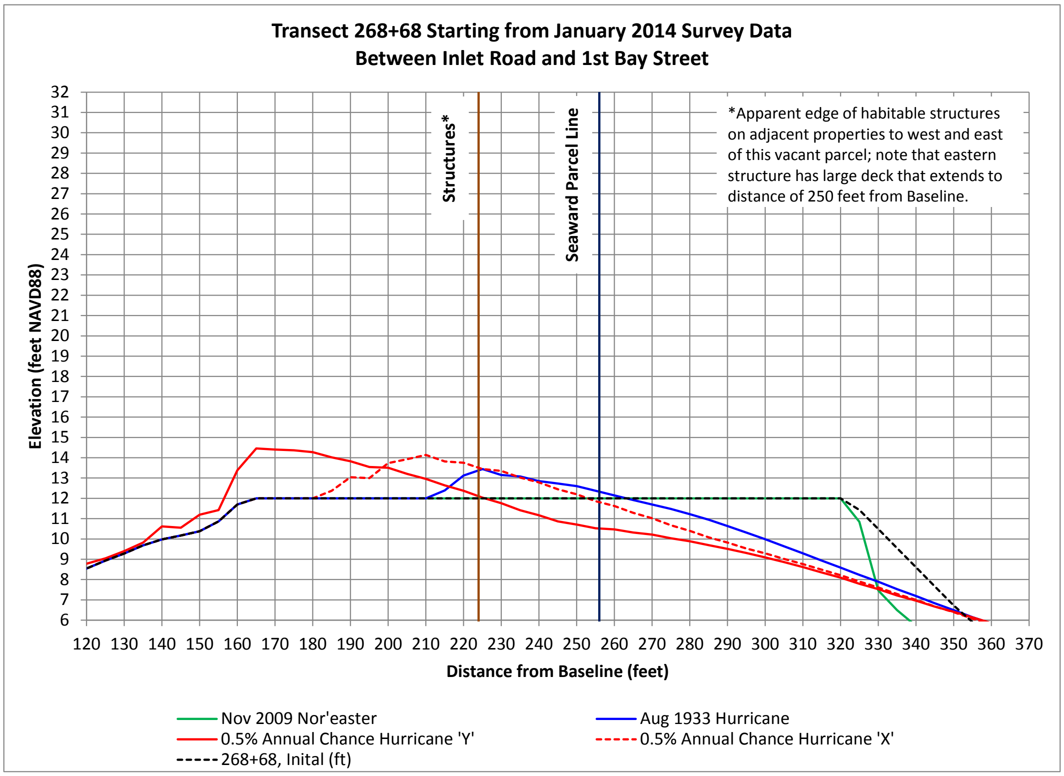

Figure 11: SBEACH results between Inlet Rd. and 1st Bay St. for dune crest at +12 ft NAVD88

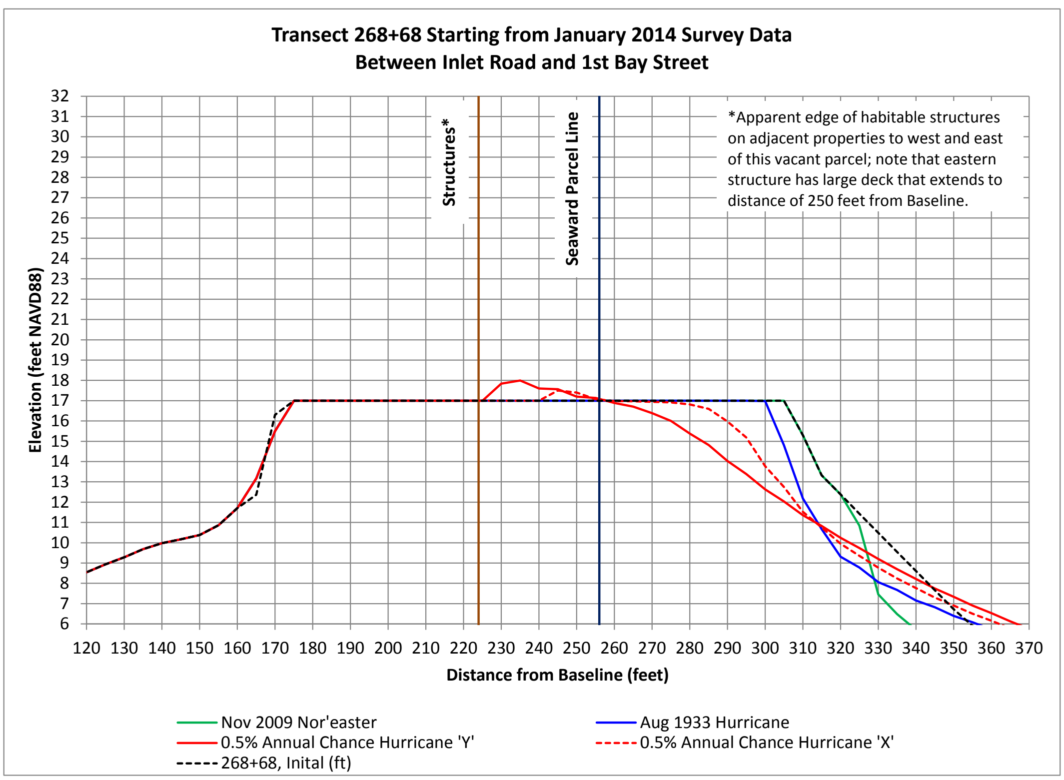

Figure 12: SBEACH results between Inlet Rd. and 1st Bay St. for dune crest at +17 ft NAVD88

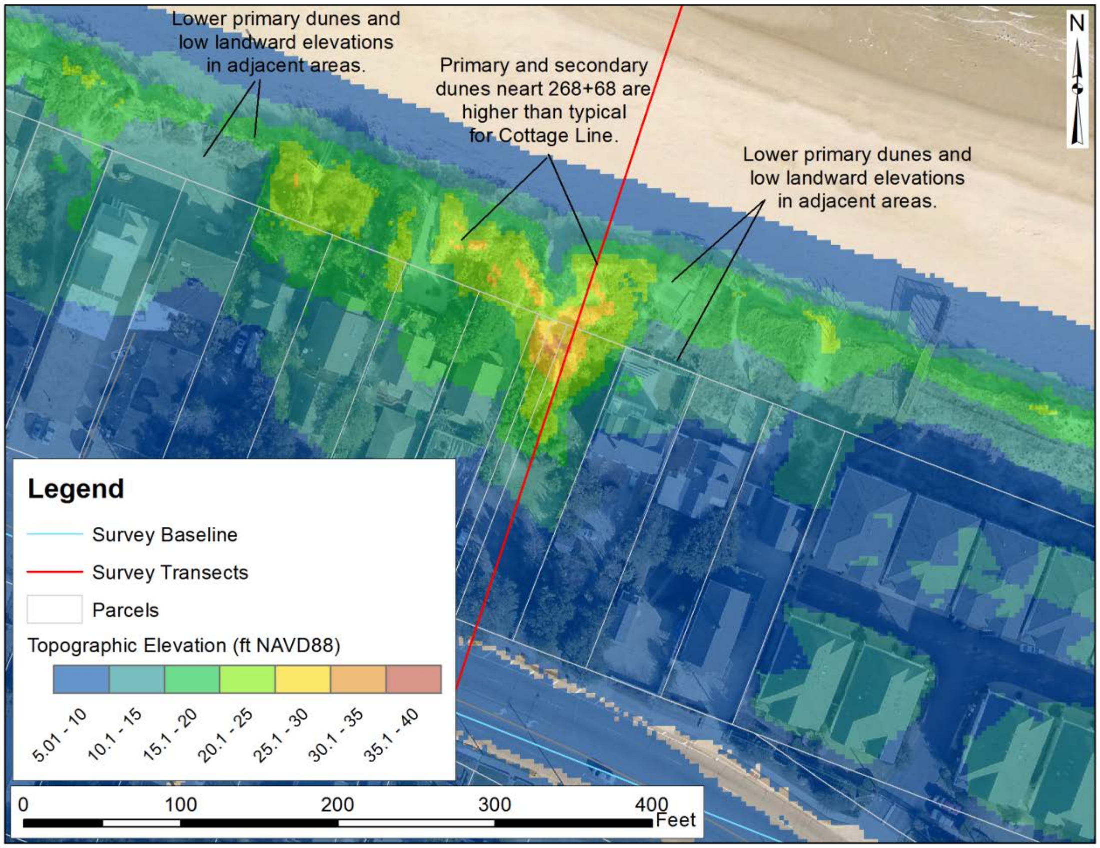

Figure 13: Dune elevations around transect 268+68 between Inlet Rd. and 1st Bay St.

Figure 14 and Figure 15 present the SBEACH results and damage potential in a graphical format, for a different perspective on the importance of the dune volume in providing coastal storm damage mitigation. Figure 14 shows markers indicating whether coastal flood damage is likely (red) or not likely (blue) for dunes of a certain volume (y-axis) for all of the storms simulated in SBEACH. The x-axis indicates storm intensity using the peak wave crest elevation on the face of the dune as a reference. Higher peak wave crests occur with higher storm surge (stillwater) elevations and/or greater wave heights approaching the shore. The chart indicates that a dune volume of at least 23 cy/LF is needed to consistently avoid increasing damage potential in the August 1933 hurricane. A greater minimum dune volume of 25 to 29 cy/LF would be required for the 0.5% annual chance Hurricane X and Hurricane Y scenarios, respectively.

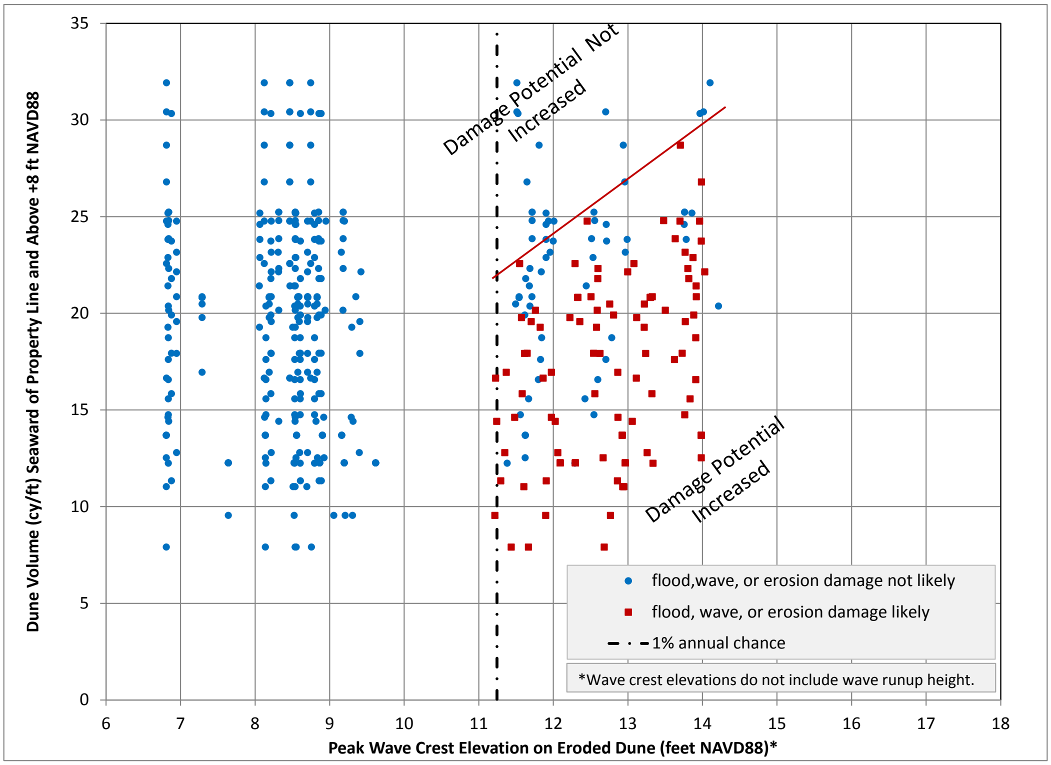

Figure 14: Flood damage potential vs. dune volumes and peak wave crest elevations

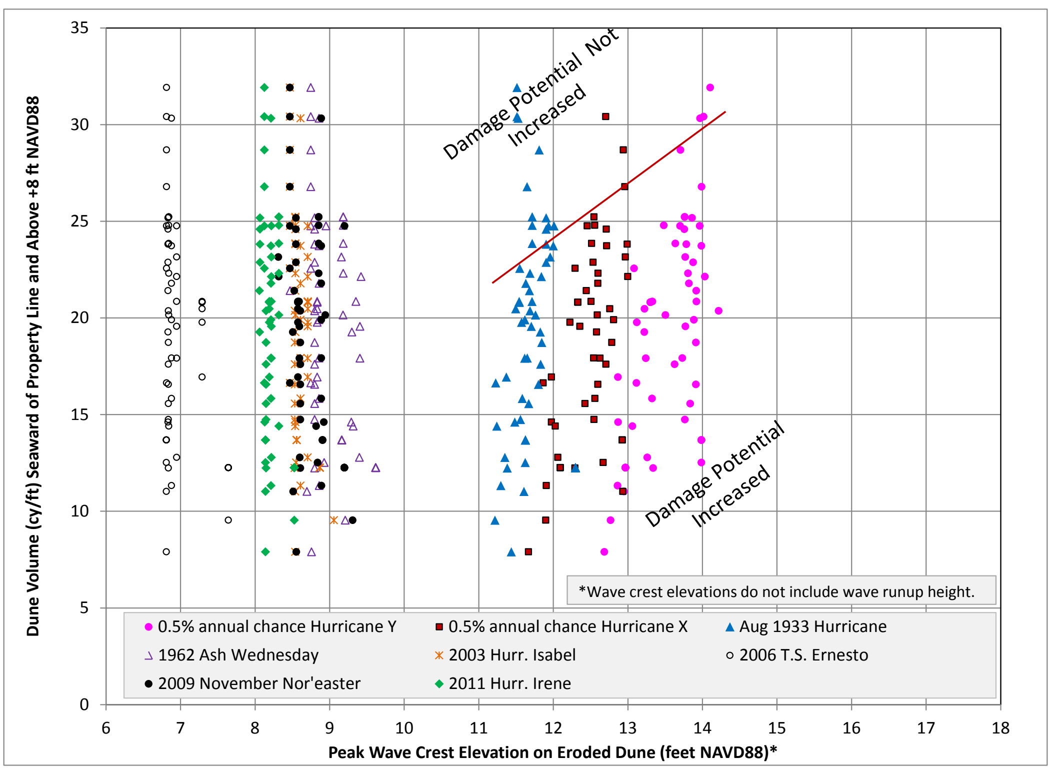

Figure 15: Peak wave crest elevations for SBEACH storms with dune volumes

Dune height remaining during the storm is as important as dune volume for mitigating inundation from storm surge and wave runup. Figure 15 shows different markers for each of the storms simulated, with x-axis and y-axis identical to Figure 14. The peak wave crests for the August 1933 hurricane approached +12 ft NAVD88 at the dune, and wave crests up to +14 ft NAVD88 were simulated for Hurricane Y. Peak wave runup elevation is typically at or above the peak wave crest elevation as the largest waves break and run up the dune face. This should be considered when making decisions regarding dune crest elevation modifications.

As noted in the introduction to this report, NFIP regulations that govern floodplain management require that the City prohibit man-made alterations of sand dunes in its V zones which would increase potential flood damage. The study results presented in this section show that, for dune crest elevations less than or equal to +17 ft NAVD88, increased risk of damage from storm surge and/or wave runup flooding would be likely for all of the transects in Cottage Line for a 0.5% annual chance Hurricane Y event. Transects near Inlet Road, 3rd Bay Street, and transect 268+68 between Inlet Road and 1st Bay Street would experience increased risk of flooding damage with dune crest elevations less than or equal to +18 ft NAVD88. Further, new preliminary FIRMs for the City of Norfolk are expected to be issued by FEMA by summer 2014, and these new FIRMs will include coastal flood hazard mapping based (partly) on the expected erosion of the existing conditions dunes. If the dunes are modified by reducing crest height or frontal dune reservoir volume, future FIRM updates may determine increased flood hazard risks, possibly resulting in increased flood insurance rates within the study area.

5. Summary and Conclusions

Moffatt & Nichol was retained by the City of Norfolk to conduct coastal engineering analyses relative to a Dune Integrity Assessment along the Cottage Line area of Ocean View in Norfolk, Virginia. More than 20 property owners have requested permission to be able to modify the dunes fronting their properties. The City needs to understand the impacts that such modifications would be likely to have on the capacity of the dunes to resist and mitigate coastal storm damage.

The purpose of the dune integrity assessment study is to evaluate the capacity of the Cottage Line beach and dune system to mitigate damage from coastal storms including erosion, flooding, and wave action. The assessment is made both for present existing dune conditions and for a range of potential dune modifications that have been proposed by Cottage Line property owners.

The study focuses on whether dune modifications would increase potential flood damage. This is specifically important because the primary dunes along Ocean View are considered by FEMA and the City of Norfolk to be located within a Coastal High Hazard Area, denoted as Zone VE on the City's FIRM. NFIP regulations outlined in 44 CFR Part 60.3(e)(7) state that the community (i.e. the City) must "prohibit man-made alterations of sand dunes and mangrove stands within Zones V1-30, VE, and V on the community's FIRM which would increase potential flood damage."

At the survey transects evaluated in this study, the existing Cottage Line dunes provide effective mitigation of storm surge and wave action for a majority of storms that have historically impacted Norfolk. Very intense storms – such as a recurrence of the historical August 1933 hurricane or a 0.5% annual chance (200-year return period) storm – would overwash or breach the dune at some locations. This would allow storm surge and wave runup to impact the properties behind the dunes.

The combination of sufficient dune height and dune volume acting together provides consistent mitigation of damage from coastal storm surges and waves. SBEACH model simulations for a range of dune height and volume modifications lead to the following conclusions:

1. Reducing the dune height to +17 ft NAVD88 would result in increased risk of flood damage over most of the study area; and

2. A dune volume of 25 to 29 cy/LF – computed above +8 ft NAVD88 and seaward of the seaward property parcel line – is required to consistently avoid increasing coastal flood damage potential in the study area.

3. These conclusions apply in present-day mean sea levels; future sea level rise would raise the dune crest elevations required to avoid increasing flood damage potential.

Any modifications to the dune faces or crest should include prompt replanting of the resulting bare sand areas according to a professionally-designed vegetation plan. Even when the dunes are vegetated (or modified and re-vegetated), the dunes are and will continue to be subject to change over time as coastal processes and human activities occur. The dunes may be "dynamically stable," oscillating around a long-term average height and volume condition. As with any other coastal flood mitigation infrastructure, it is wise to allow for this variability in setting design elevations for dunes. Engineers and planners speak of this as providing "freeboard," for example an additional 1 foot to 2 feet on top of the minimum required elevation.

Dune modification proposals that include lowering the dune crest elevation then placing the removed volume on the seaward face of the dune (at lower elevations) would not necessarily provide protection equivalent to the existing conditions. The ultimate extent of erosion damage experienced by a dune in a storm is generally considered to depend on the volume of sand in the dune above the storm's stillwater elevation. Sand removed from the top of the dune and placed below +8 feet NAVD88 would not be as effective in providing storm damage protection as the sand already in the upper levels of the dune. Additionally, if modifications are done over short stretched (such as a typical property parcel width), the sand placed on the seaward dune face is subject to redistribution by natural processes to adjacent properties and upward or downward on the dune face. This would result in a reduction of the dune volume above +8 feet NAVD88 available at that location. Any proposal to modify the dune by removing volume from the crest and placing that volume in other parts of the dune should be reviewed by a qualified professional on a case-by-case basis.

This coastal engineering study is only one component of the coordination necessary in evaluating the residents' proposed dune modifications. It is recommended that the City coordinate with federal agencies such as FEMA and USACE, along with relevant Virginia agencies, to discuss implications relative to floodplain management, flood insurance rates, federal hazard mitigation project assistance, and State dune management regulations.

6. References

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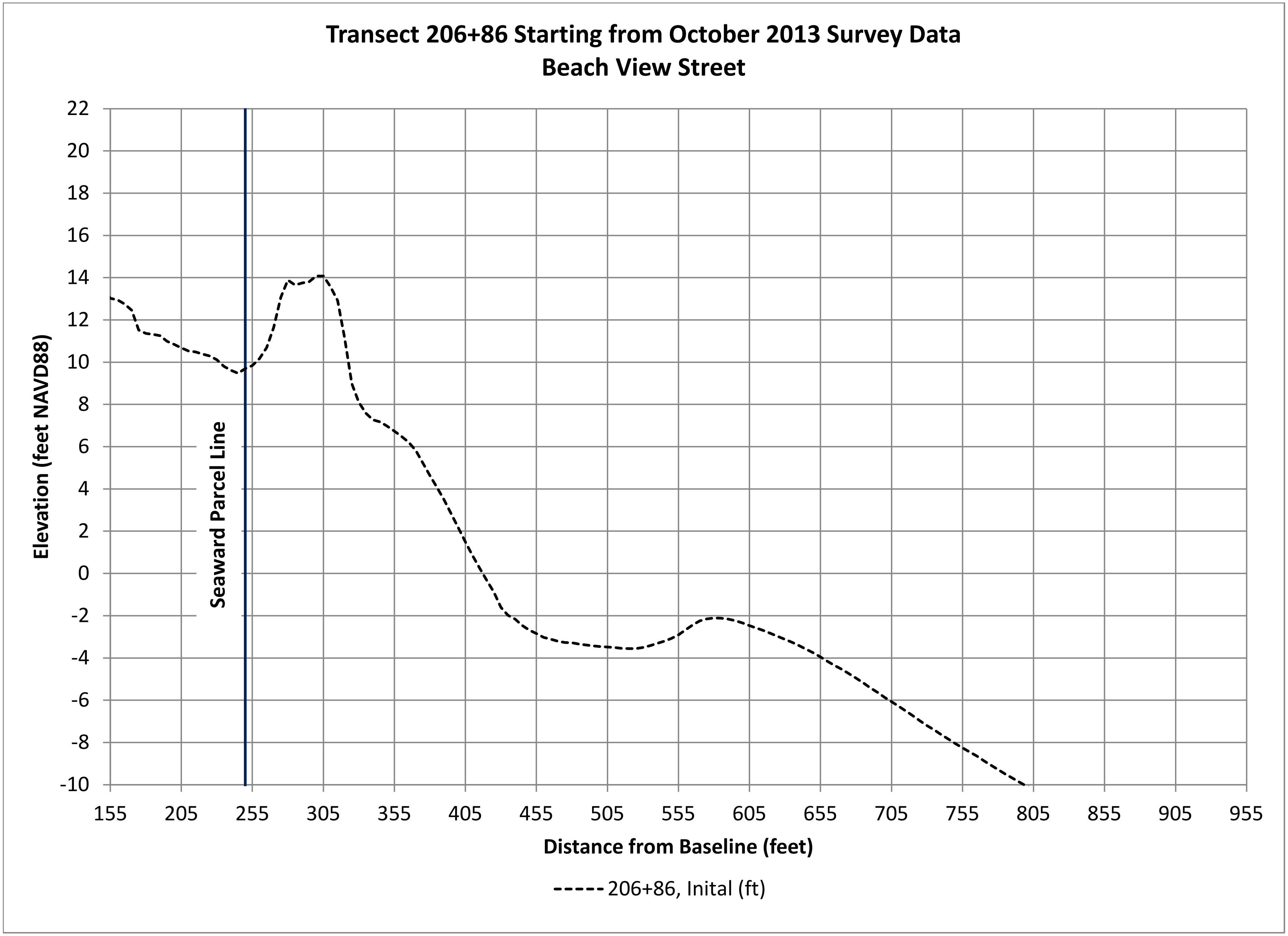
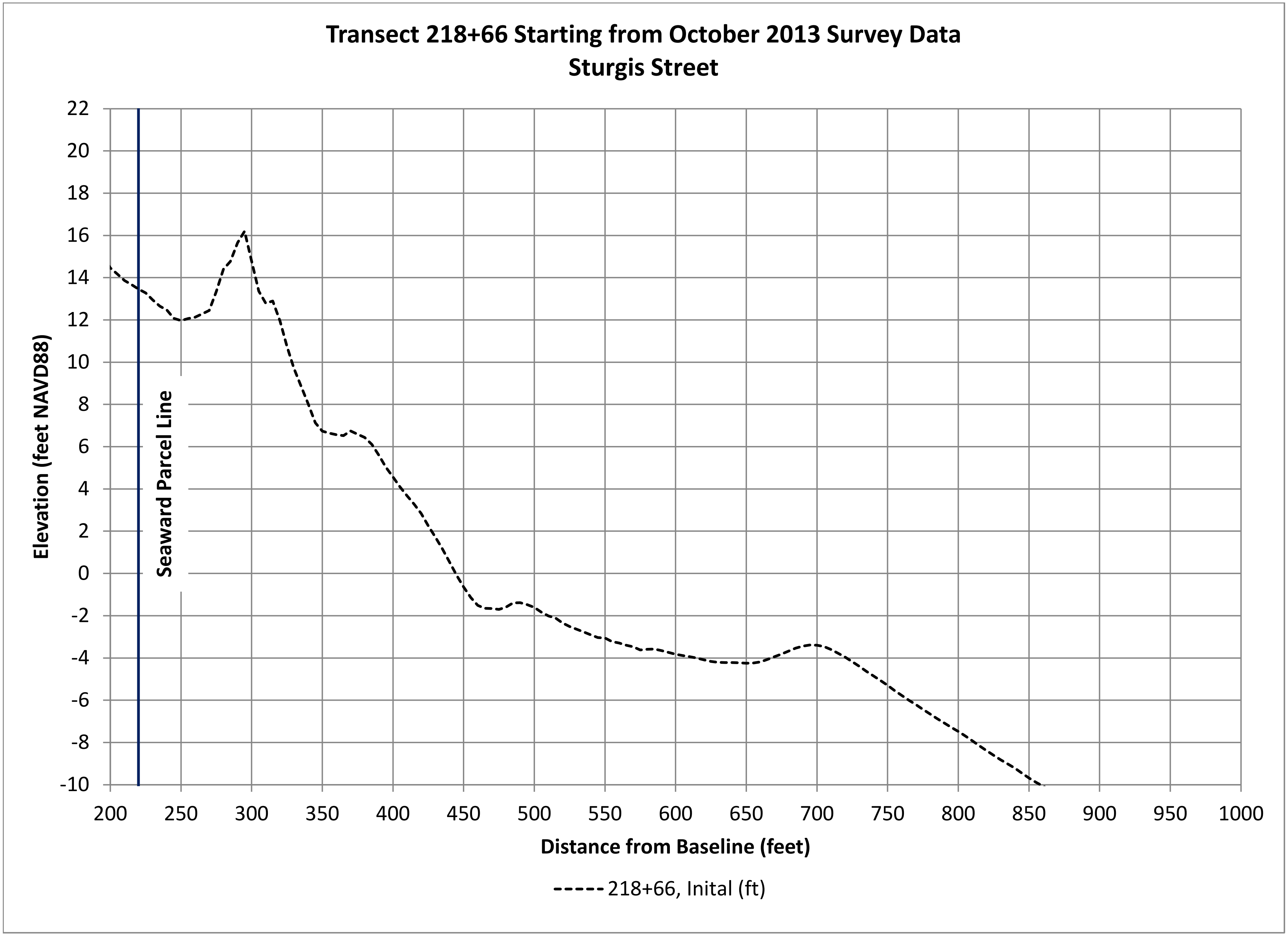
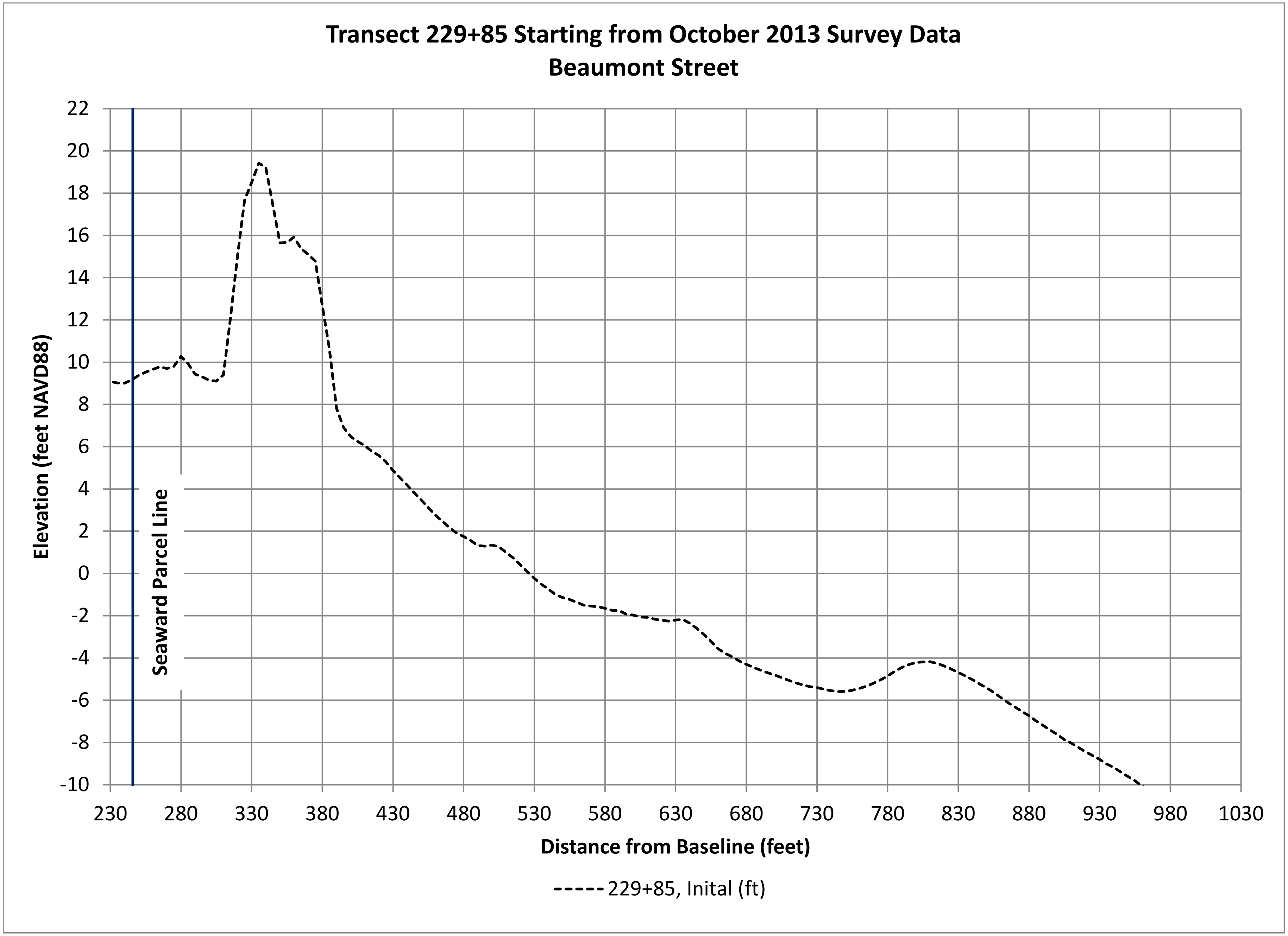
Appendix A: Existing Condition Beach and Dune Profiles



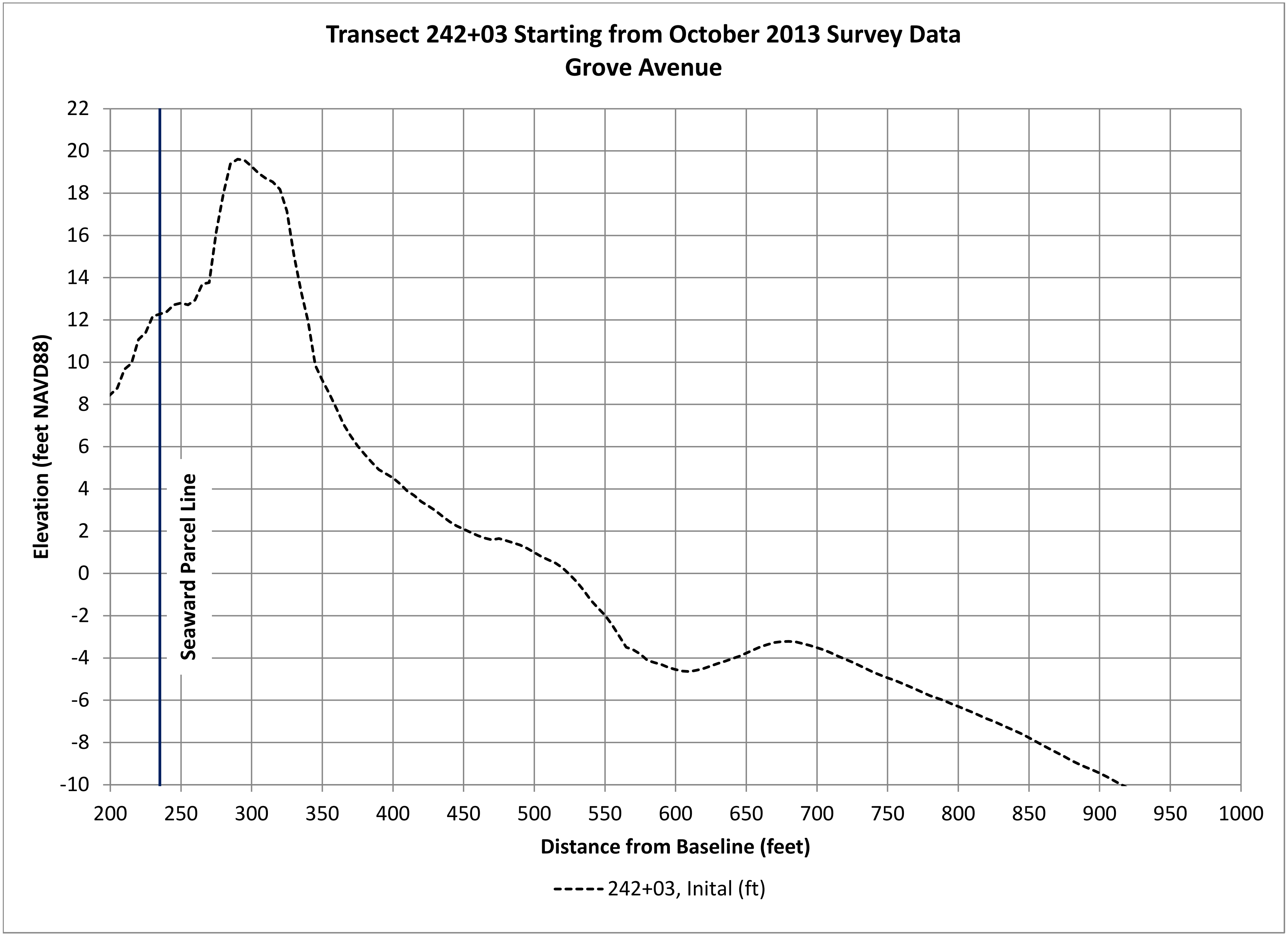
Each grid box = 100 sq. ft./LF,
approximately 3.7 cy/LF



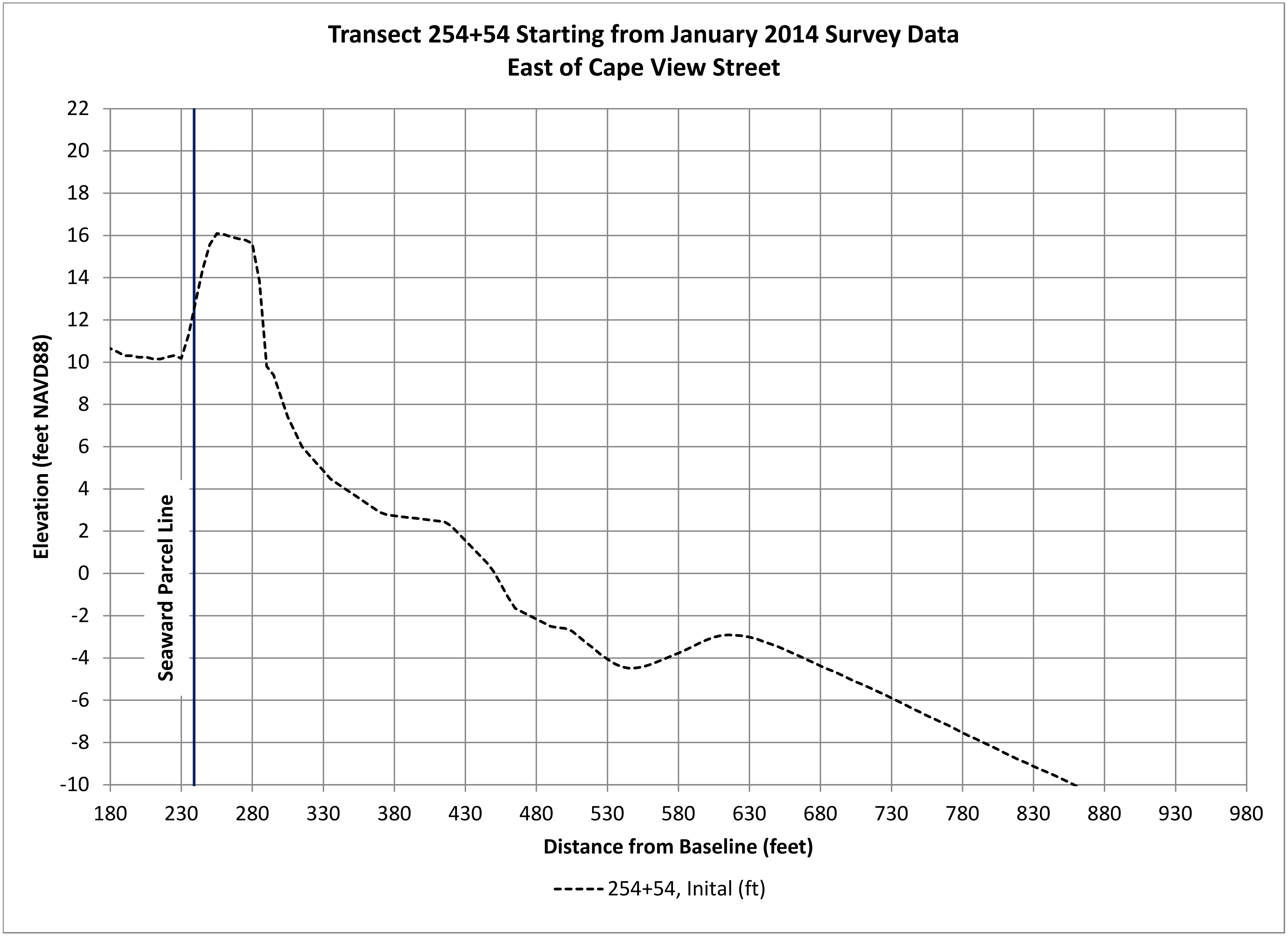
Each grid box = 100 sq. ft./LF,
approximately 3.7 cy/LF



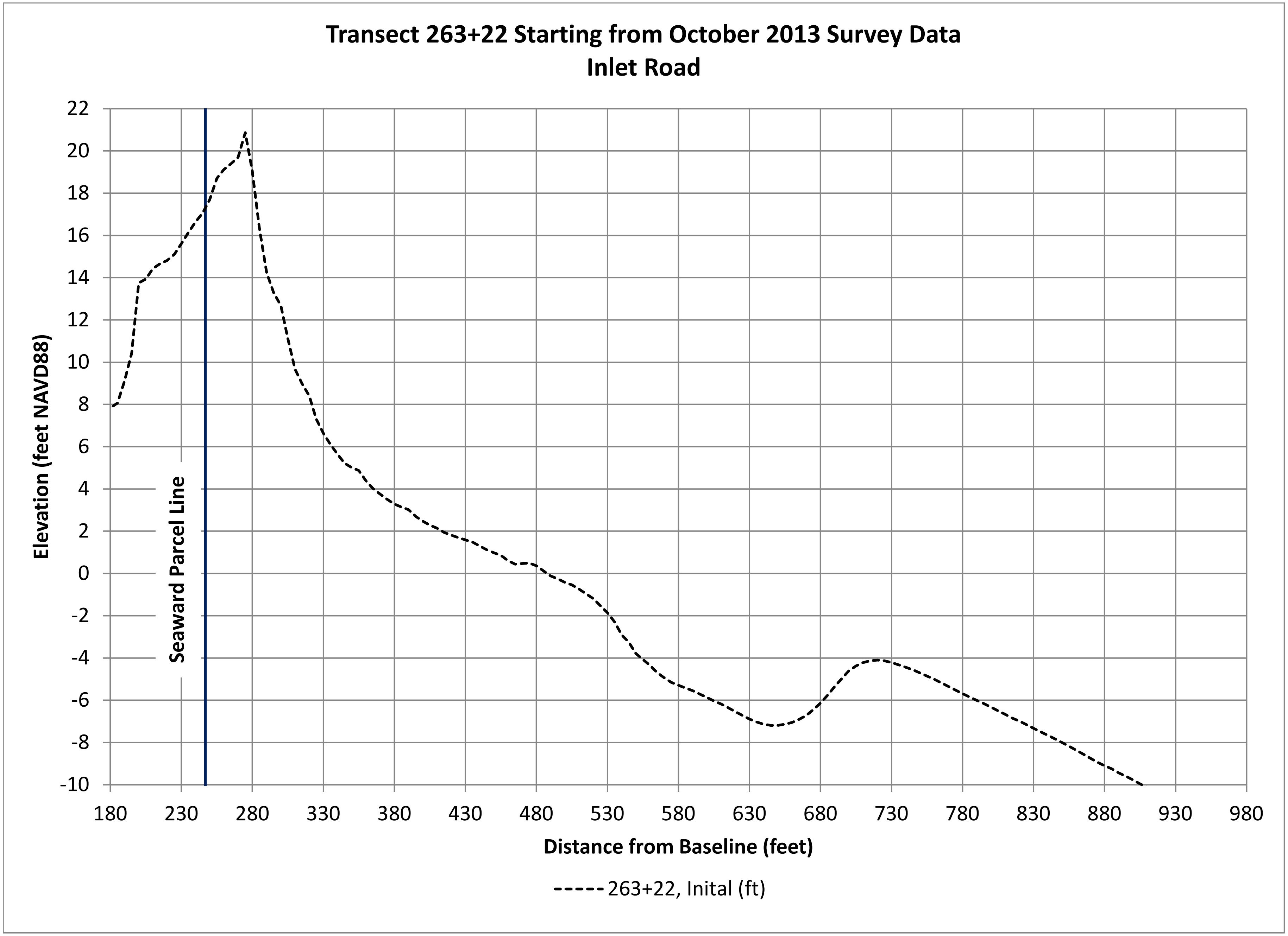
Each grid box = 100 sq. ft./LF,
approximately 3.7 cy/LF



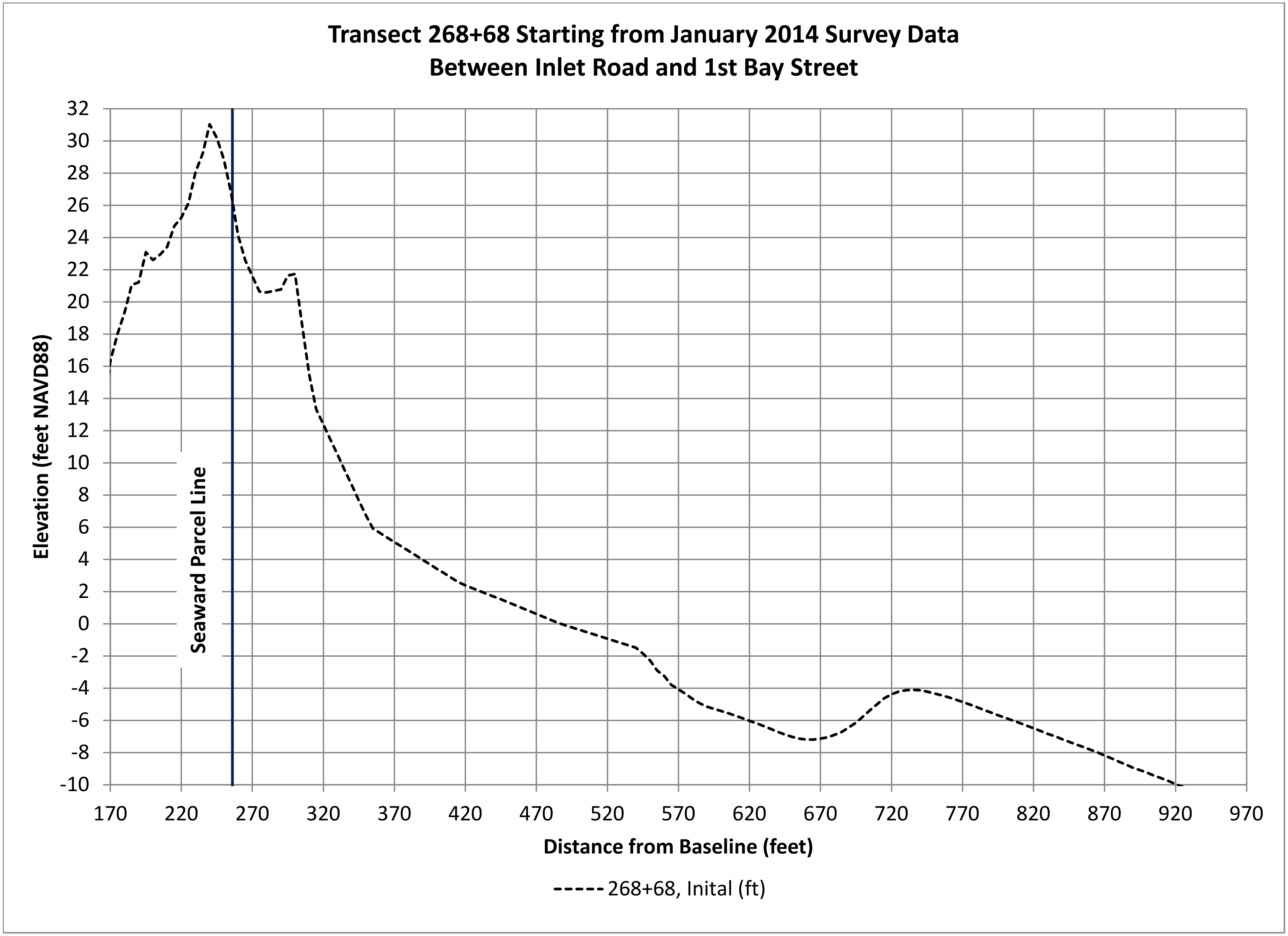
Each grid box = 100 sq. ft./LF,
approximately 3.7 cy/LF



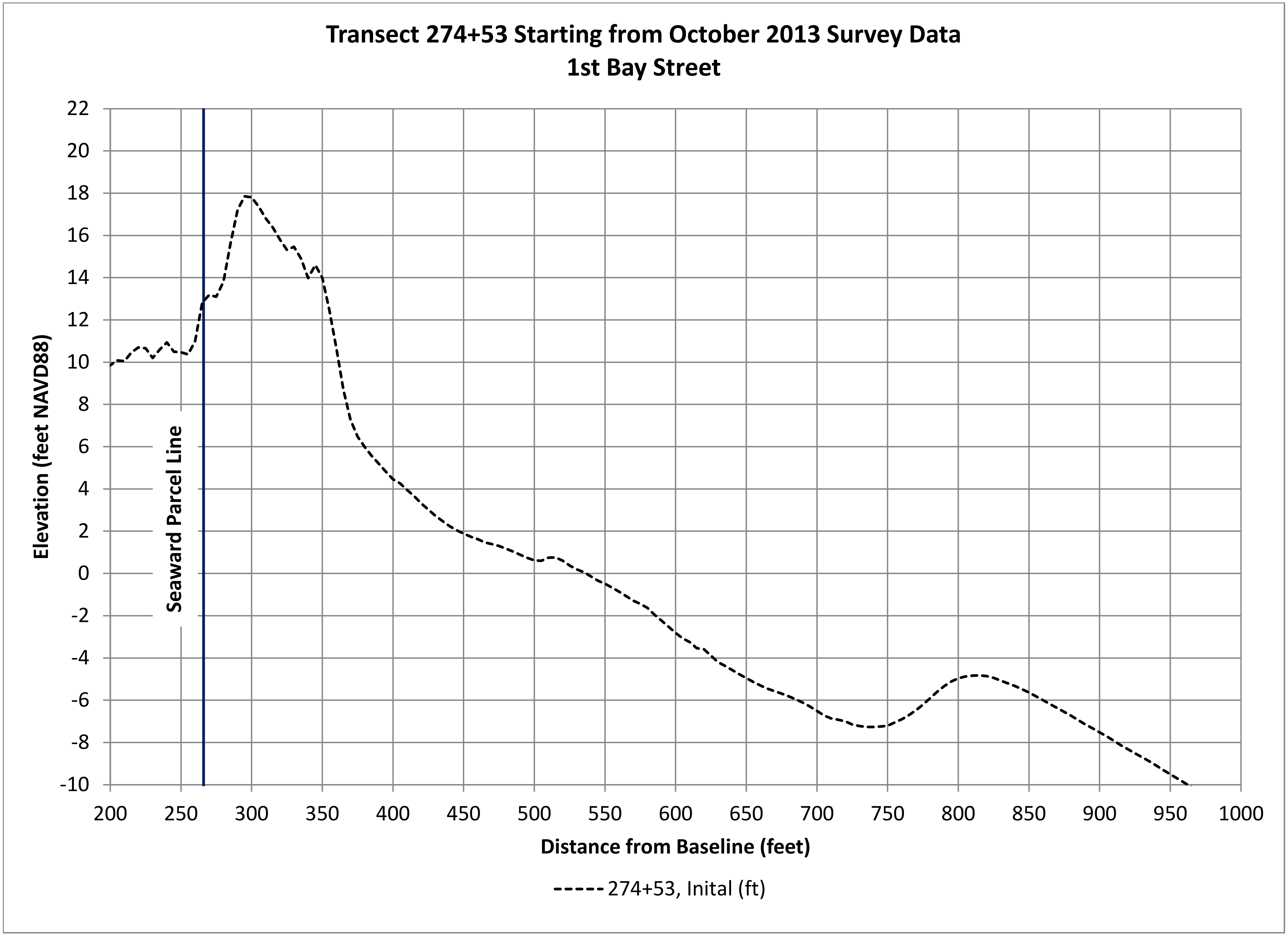
Each grid box = 100 sq. ft./LF,
approximately 3.7 cy/LF



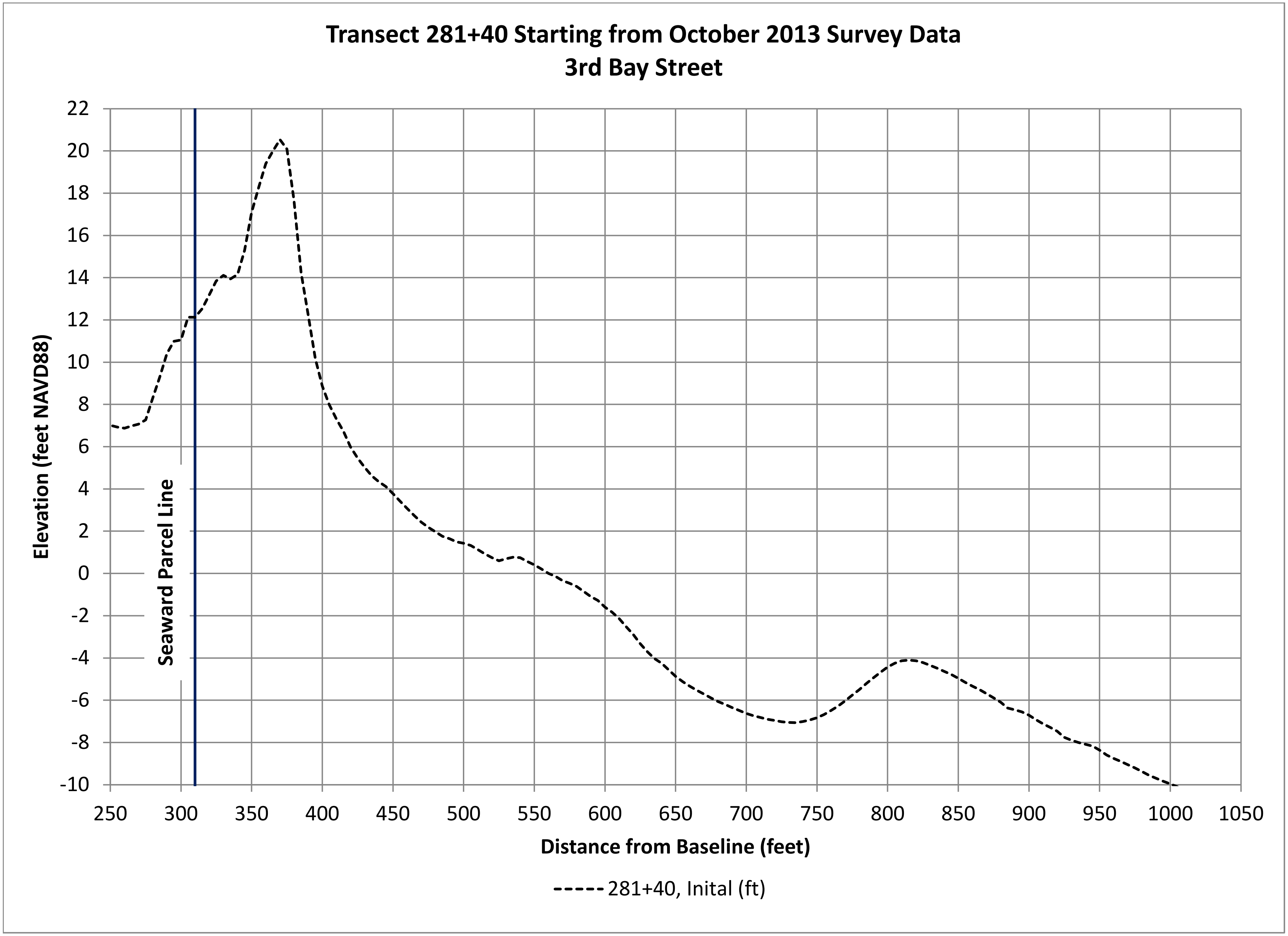
Each grid box = 100 sq. ft./LF,
approximately 3.7 cy/LF



Each grid box = 100 sq. ft./LF,
approximately 3.7 cy/LF

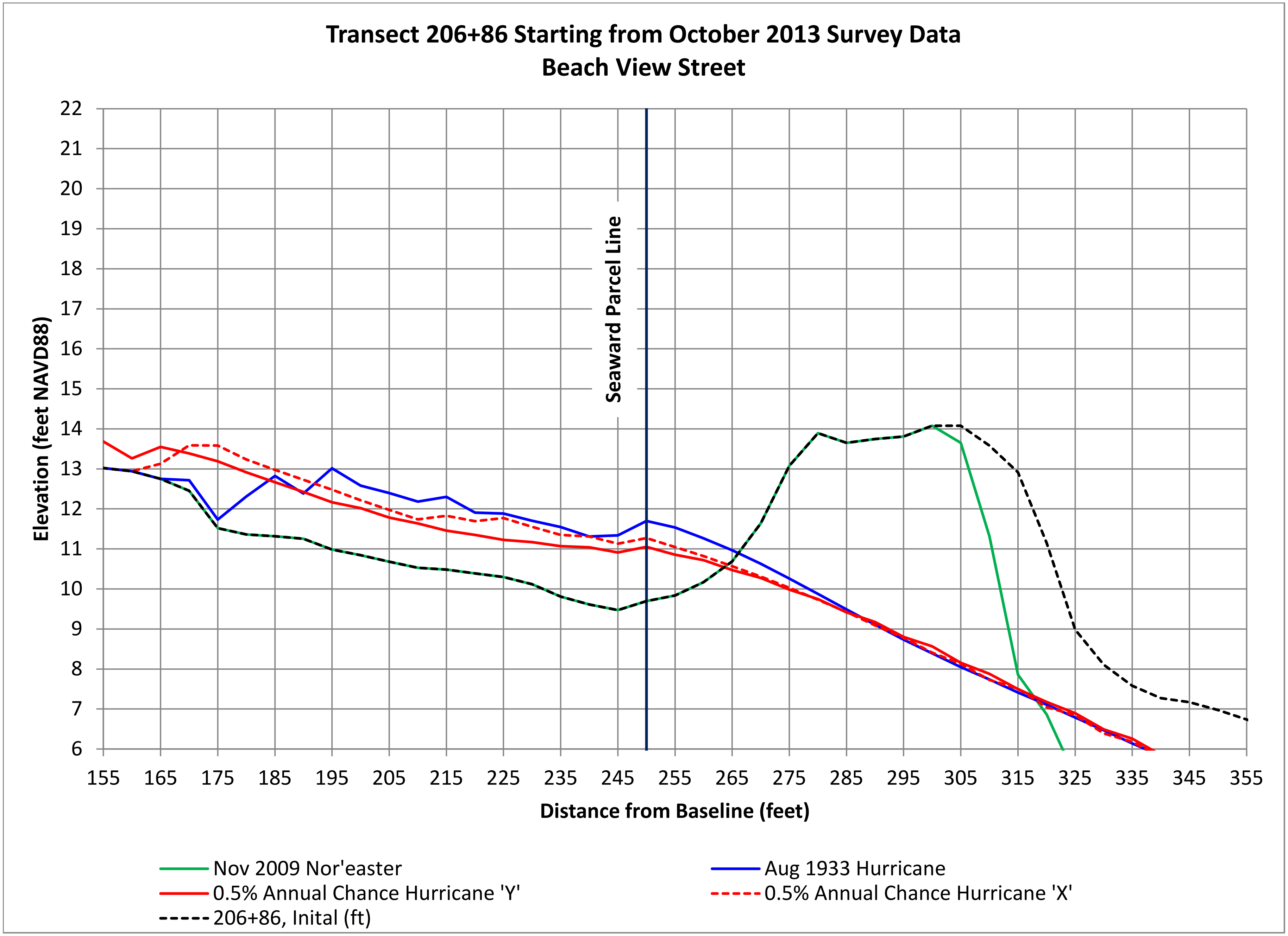


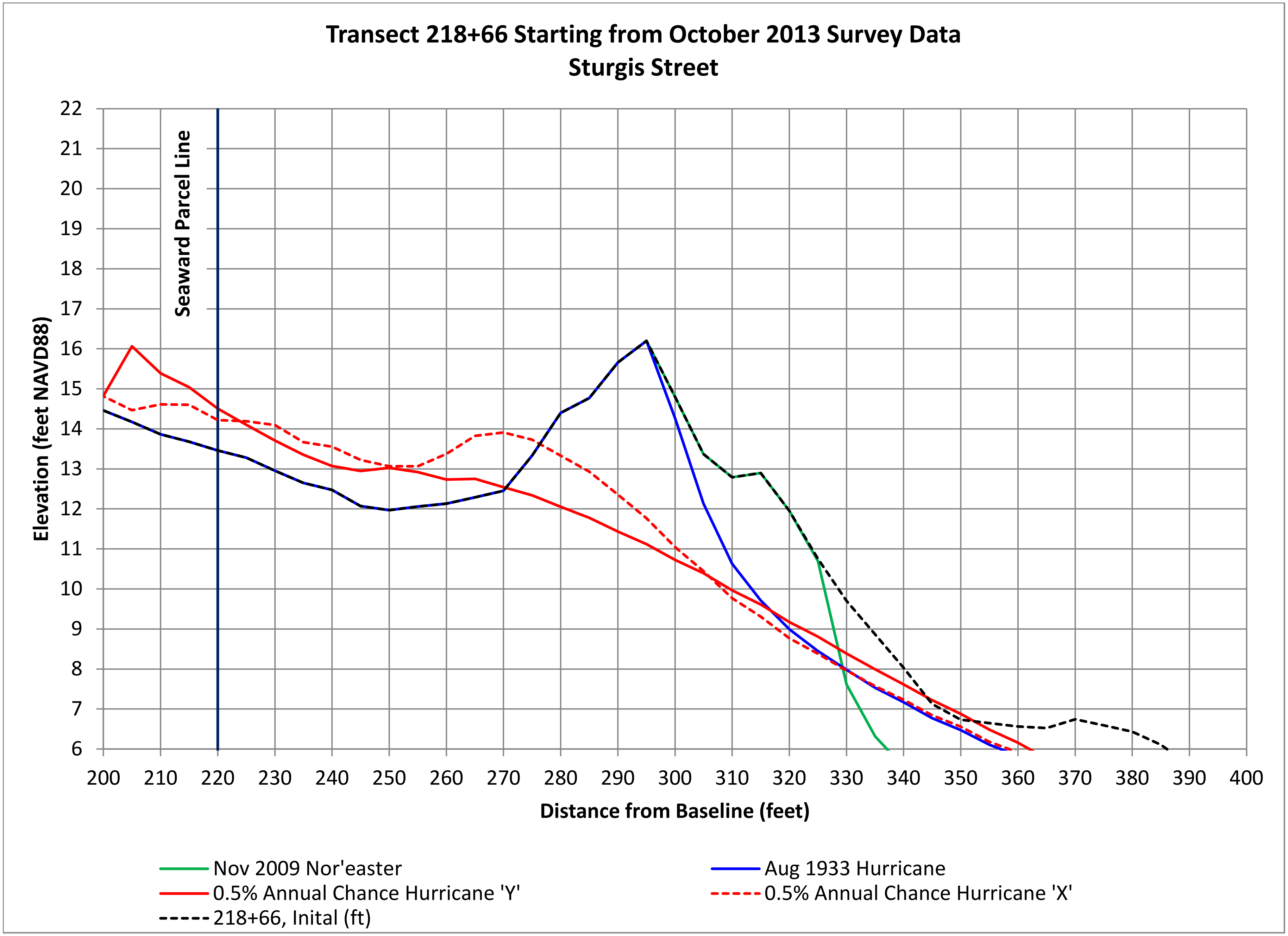
Each grid box = 100 sq. ft./LF,
approximately 3.7 cy/LF

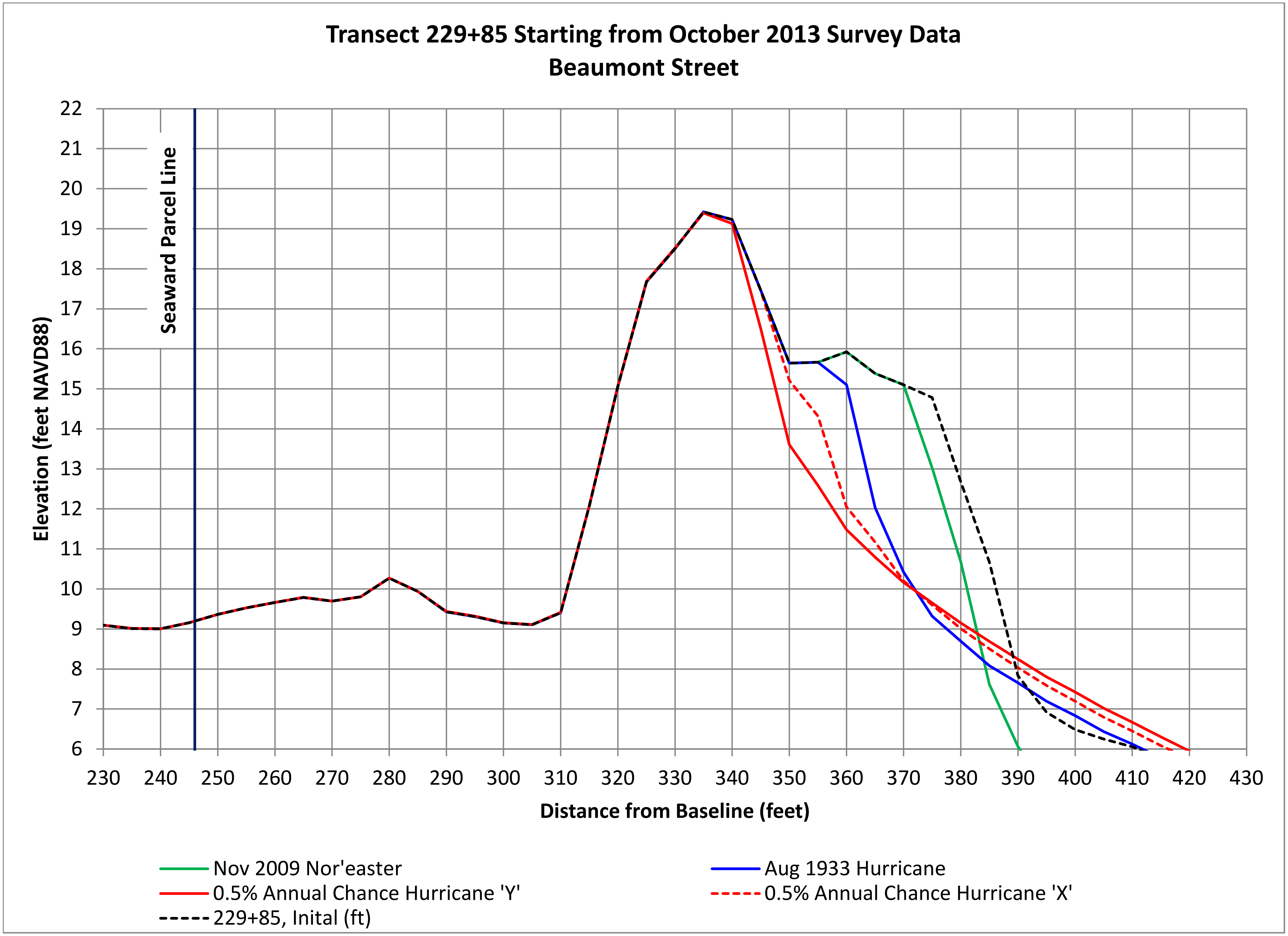


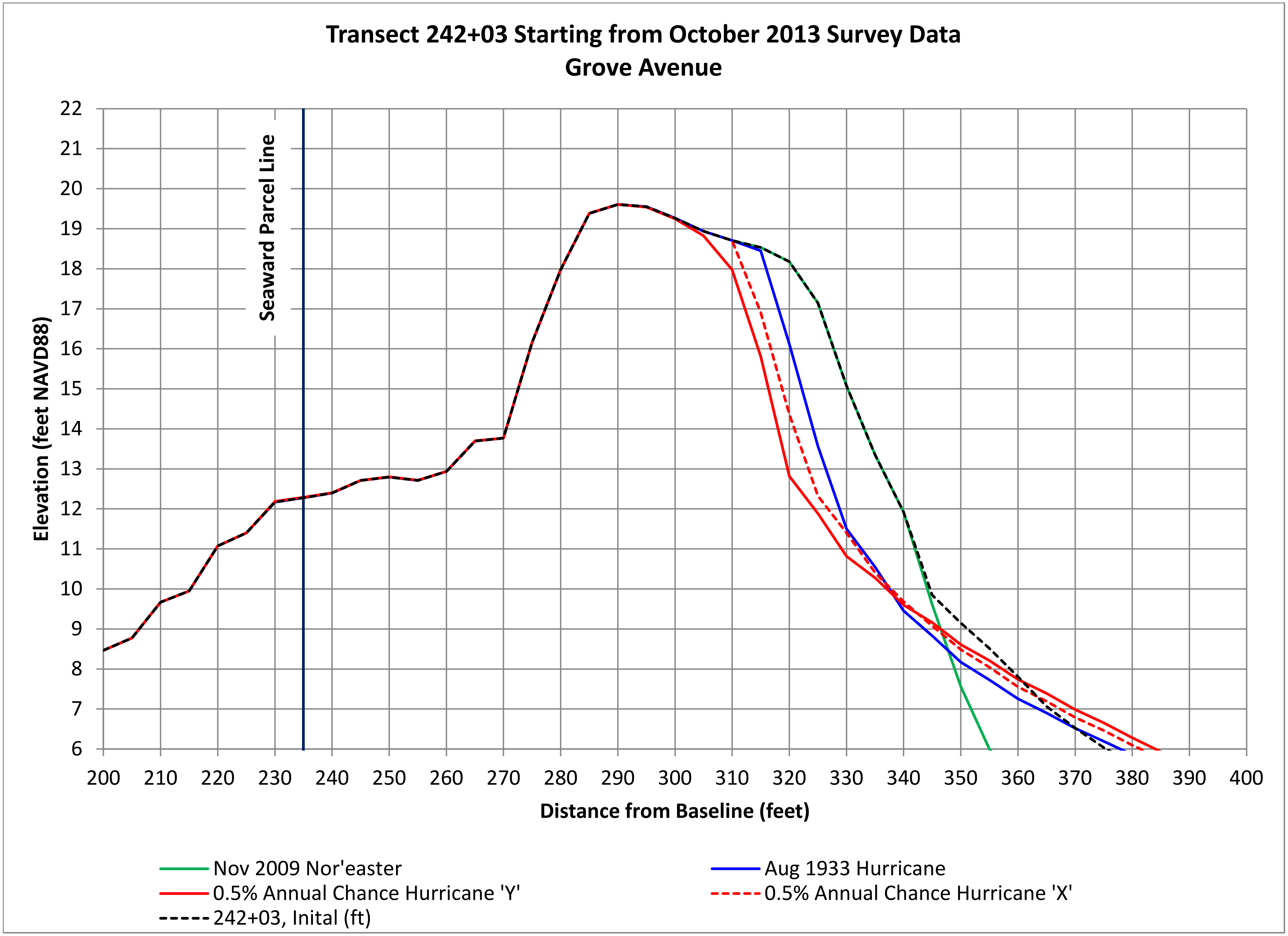
Each grid box = 100 sq. ft./LF,
approximately 3.7 cy/LF

Appendix B: SBEACH Storm Erosion Results, Existing Conditions

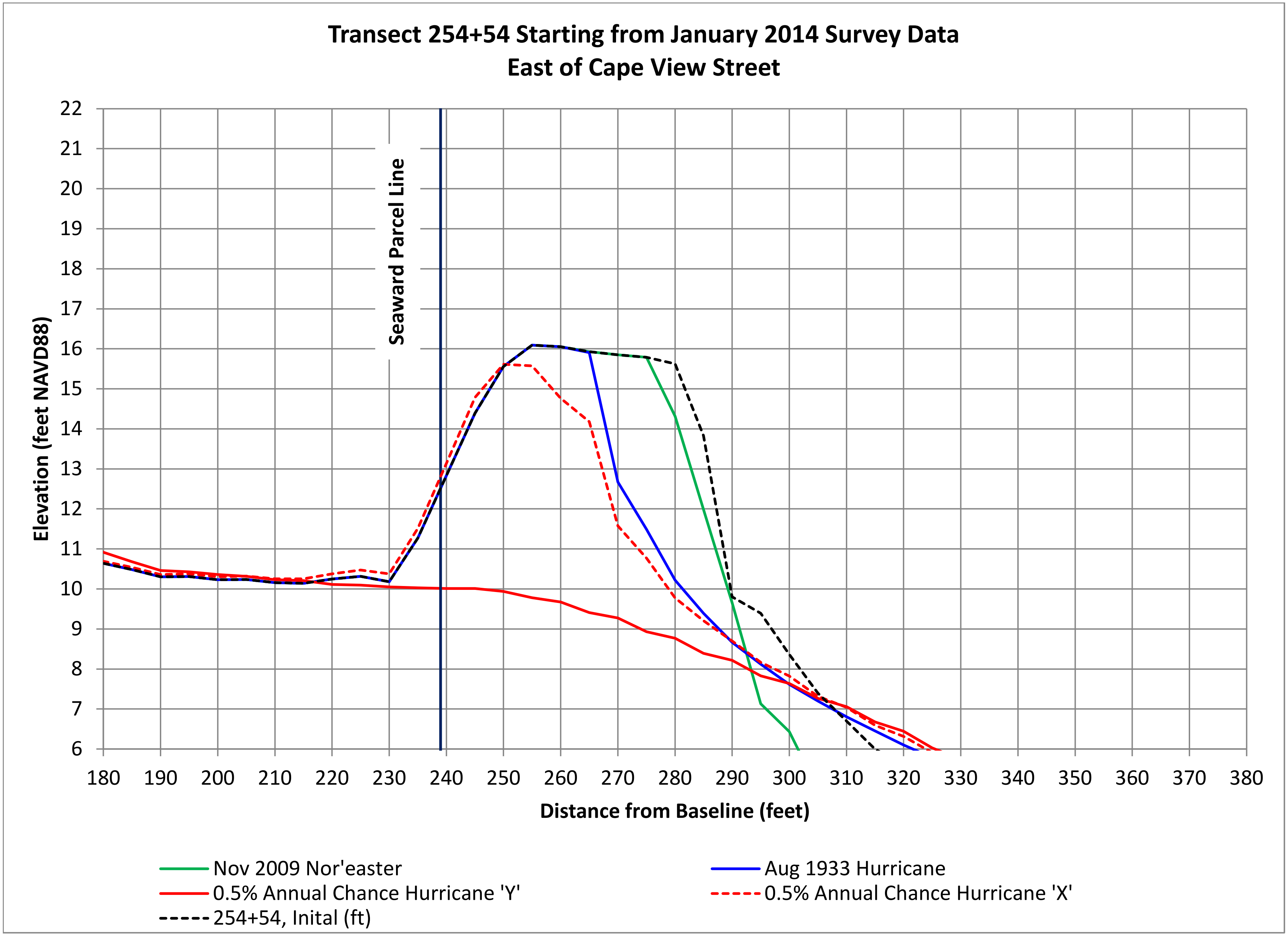

Transect 206+86 Starting from October 2013 Survey Data
Beach View Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
155
165
175
185
195
205
215
225
235
245
255
265
275
285
295
305
315
325
335
345
355
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
206+86, Inital (ft)

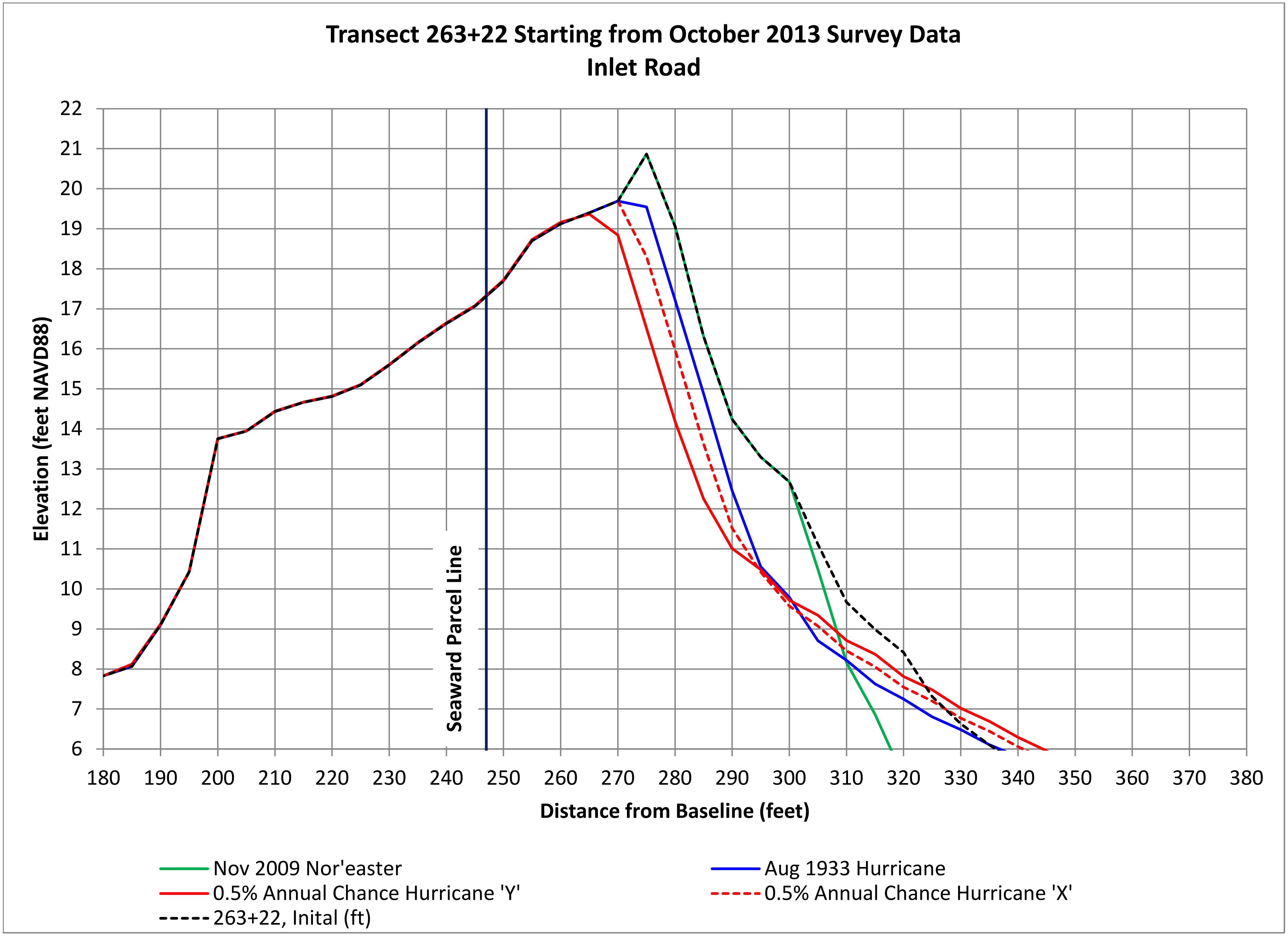

Transect 218+66 Starting from October 2013 Survey Data
Sturgis Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
218+66, Inital (ft)

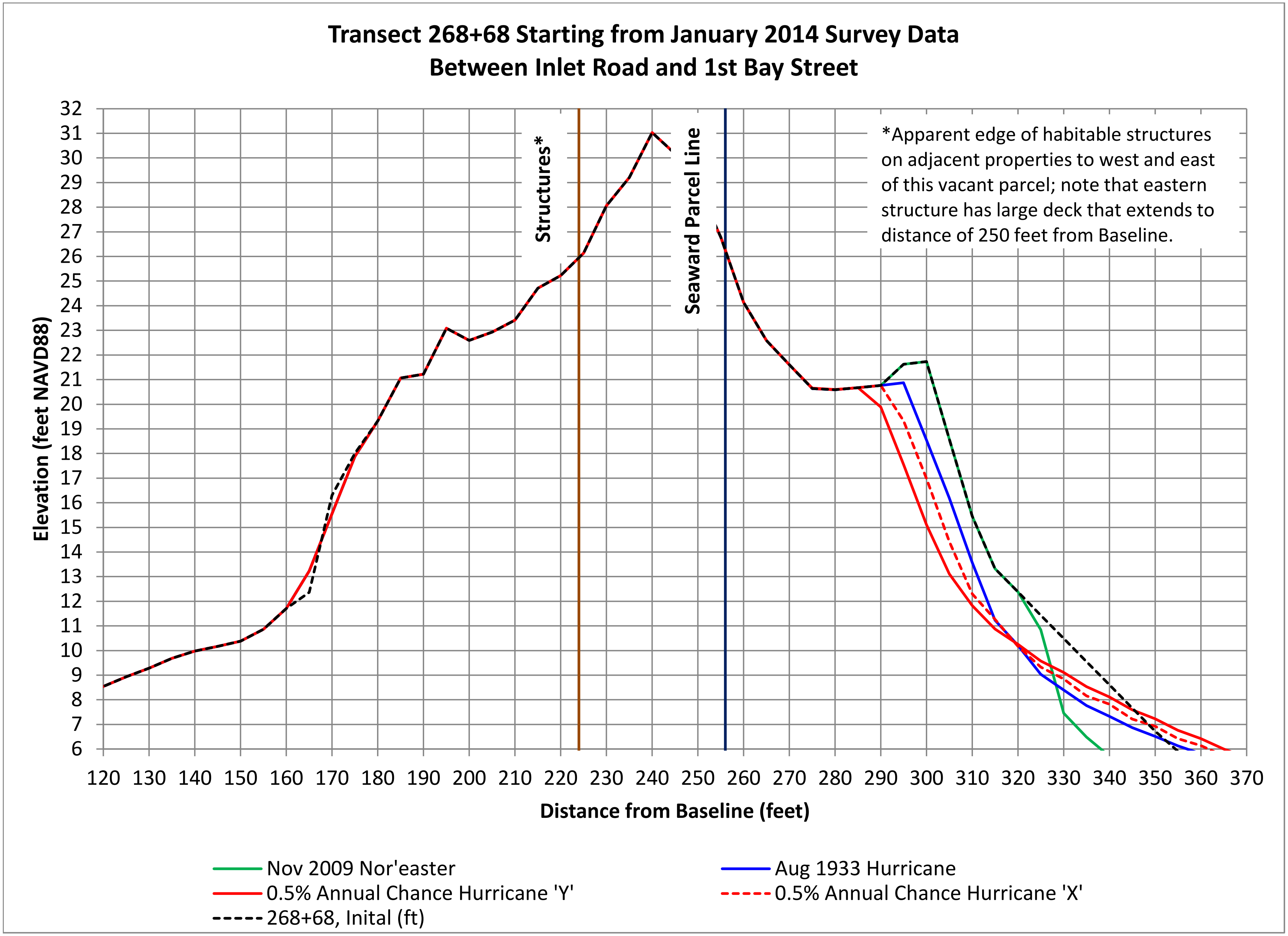

Transect 229+85 Starting from October 2013 Survey Data
Beaumont Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
430
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
229+85, Inital (ft)

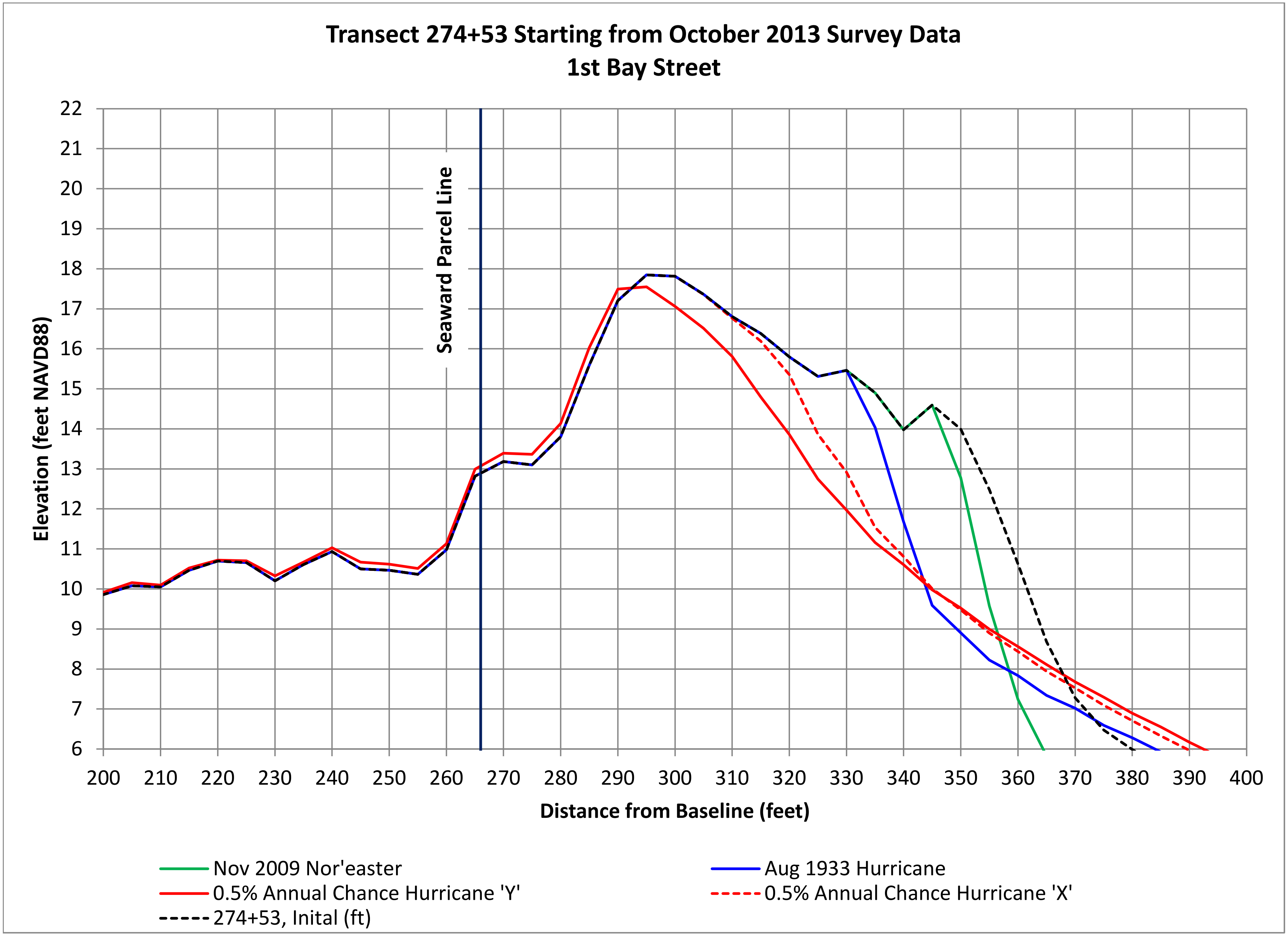


Transect 242+03 Starting from October 2013 Survey Data
Grove Avenue
Seaward Parcel Line
Elevation (feet NAVD88)
Distance from Baseline (feet)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
242+03, Inital (ft)

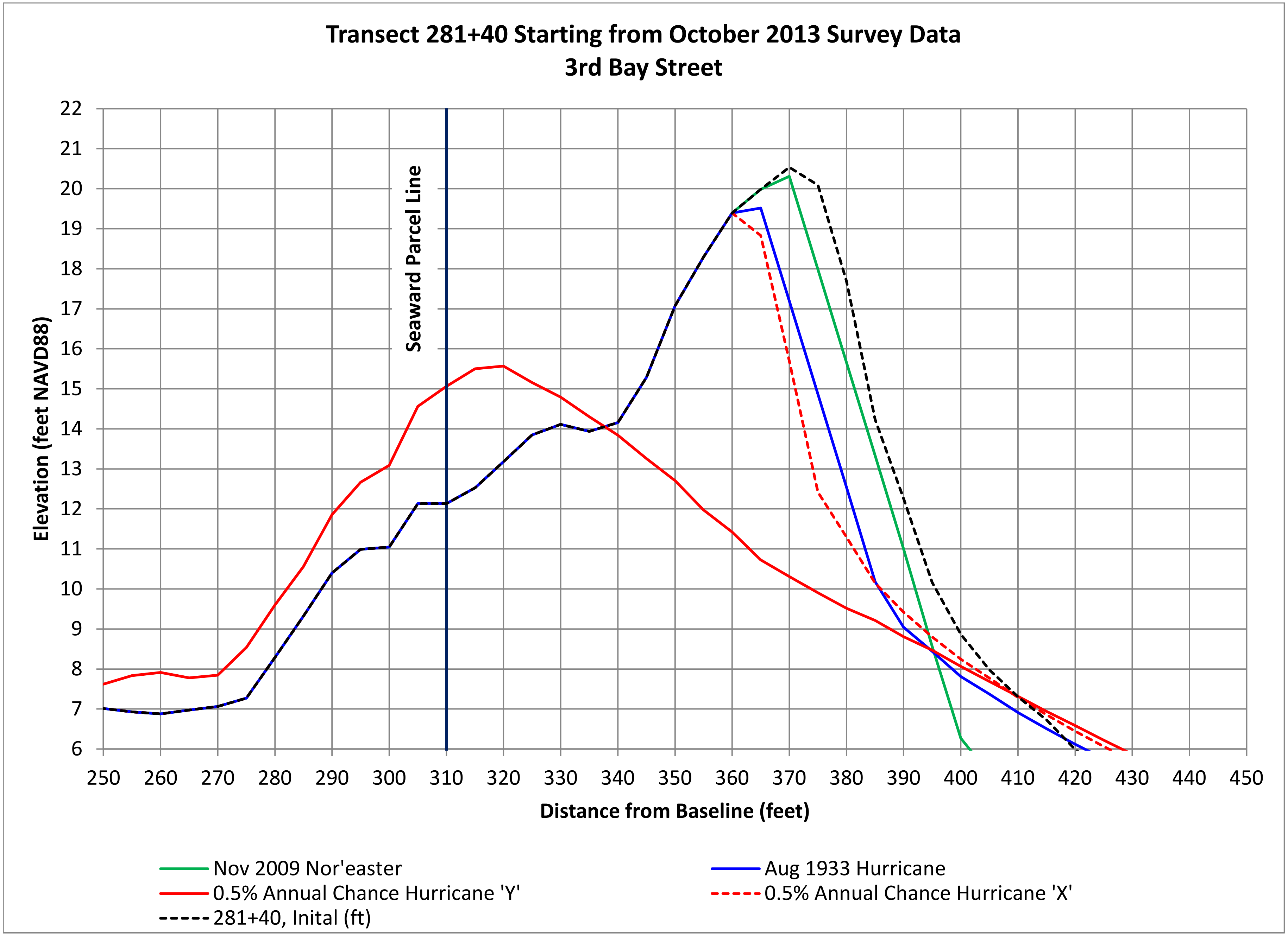

Transect 254+54 Starting from January 2014 Survey Data
East of Cape View Street
Seaward Parcel Line
Elevation (feet NAVD88)
Distance from Baseline (feet)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
254+54, Inital (ft)


Transect 263+22 Starting from October 2013 Survey Data
Inlet Road
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
Seaward Parcel Line
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
263+22, Inital (ft)

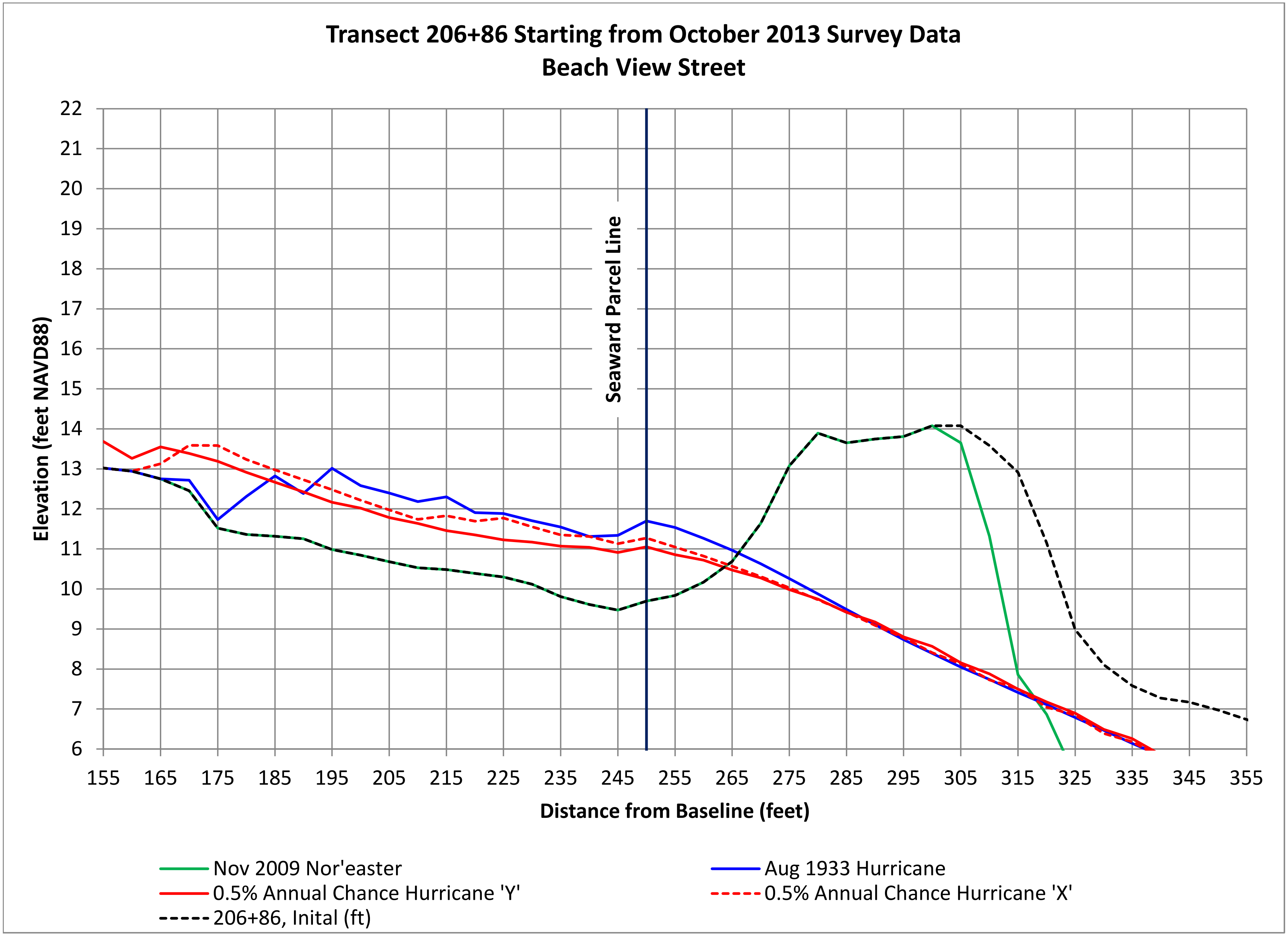

Transect 268+68 Starting from January 2014 Survey Data
Between Inlet Road and 1st Bay Street
Structures*
Seaward Parcel Line
*Apparent edge of habitable structures on adjacent properties to west and east of this vacant parcel; note that eastern structure has large deck that extends to distance of 250 feet from Baseline.
Elevation (feet NAVD88)
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
268+68, Inital (ft)

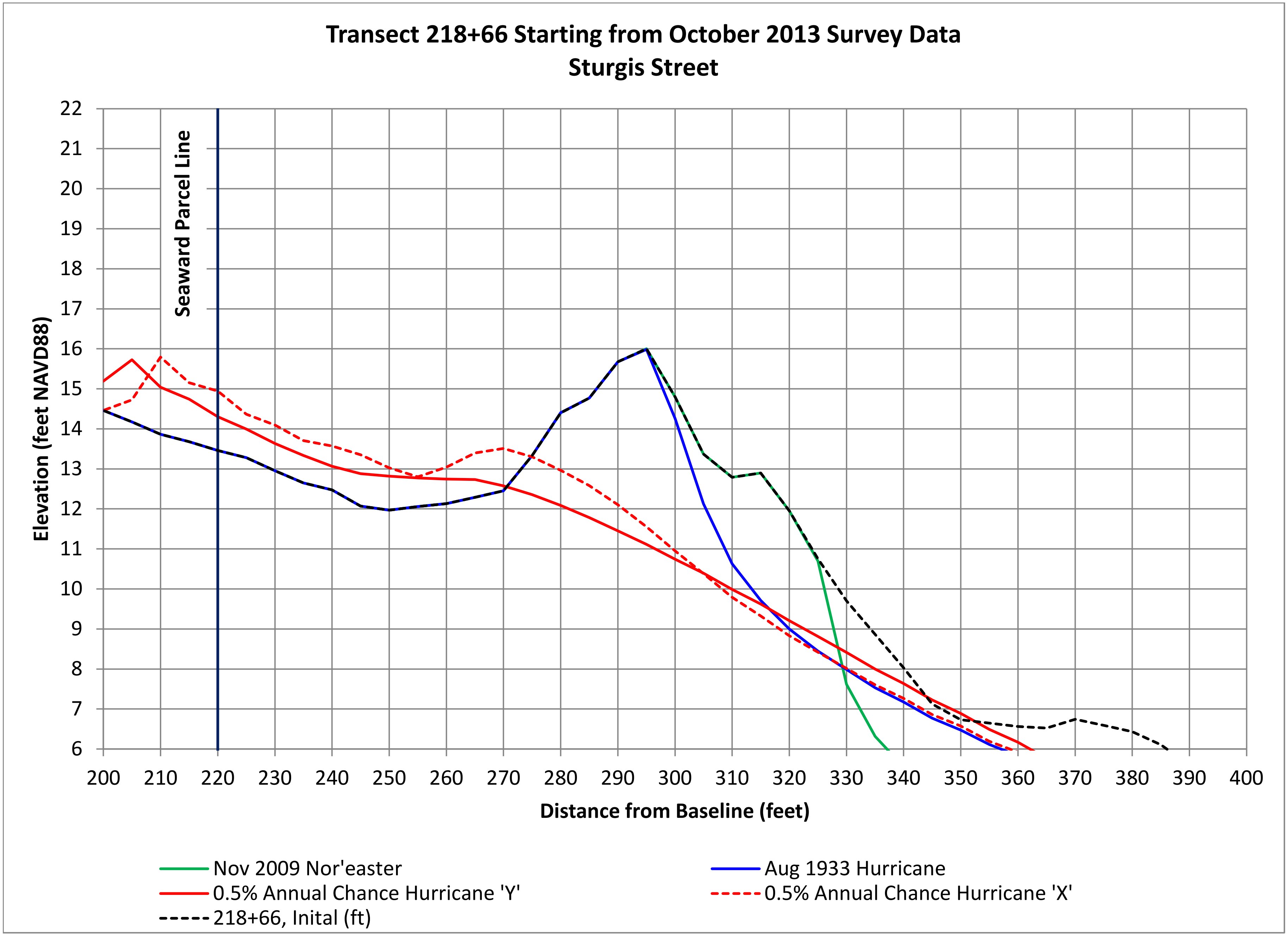


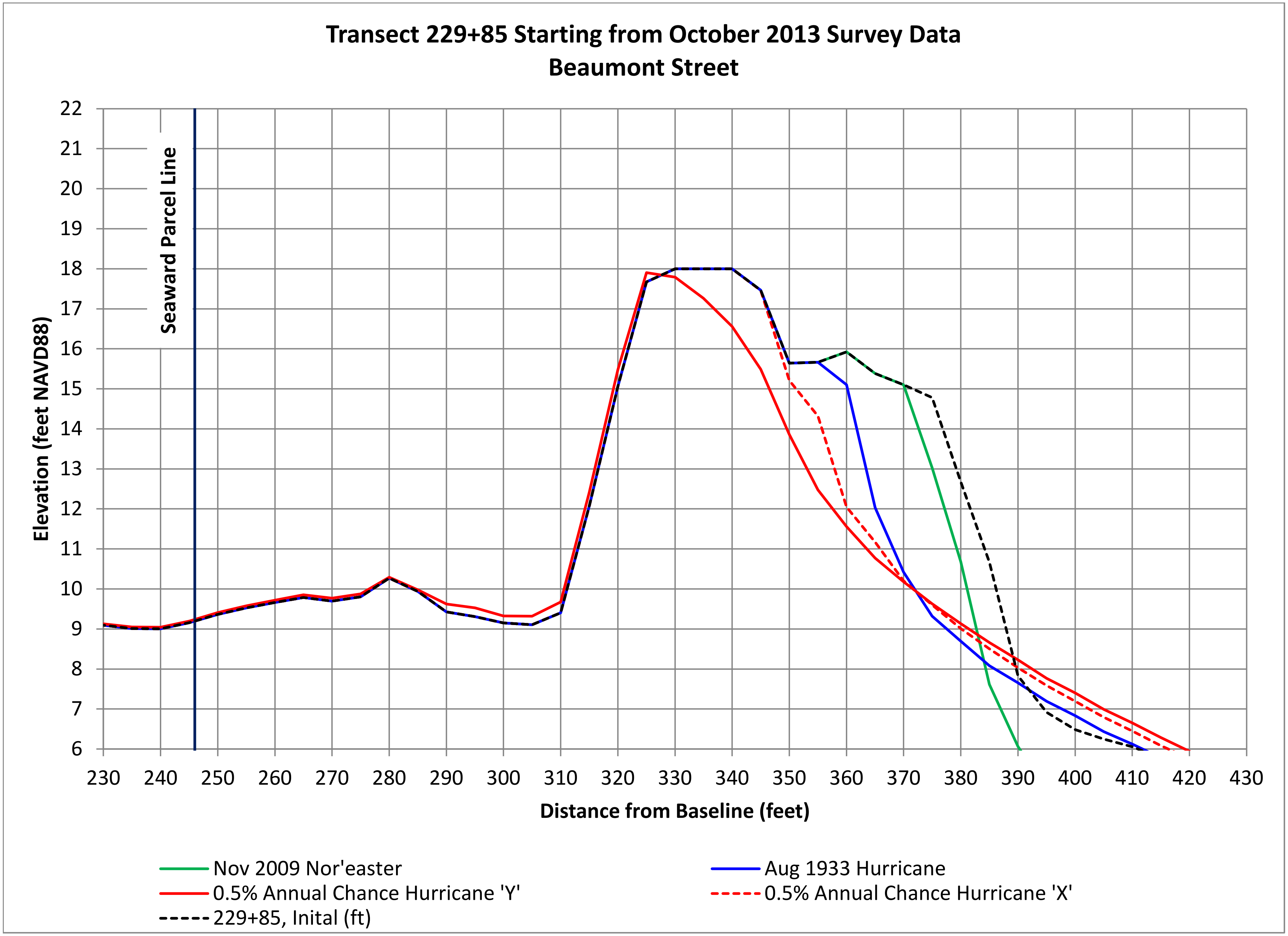
Transect 274+53 Starting from October 2013 Survey Data
1st Bay Street
Seaward Parcel Line
Elevation (feet NAVD88)
Distance from Baseline (feet)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
274+53, Inital (ft)

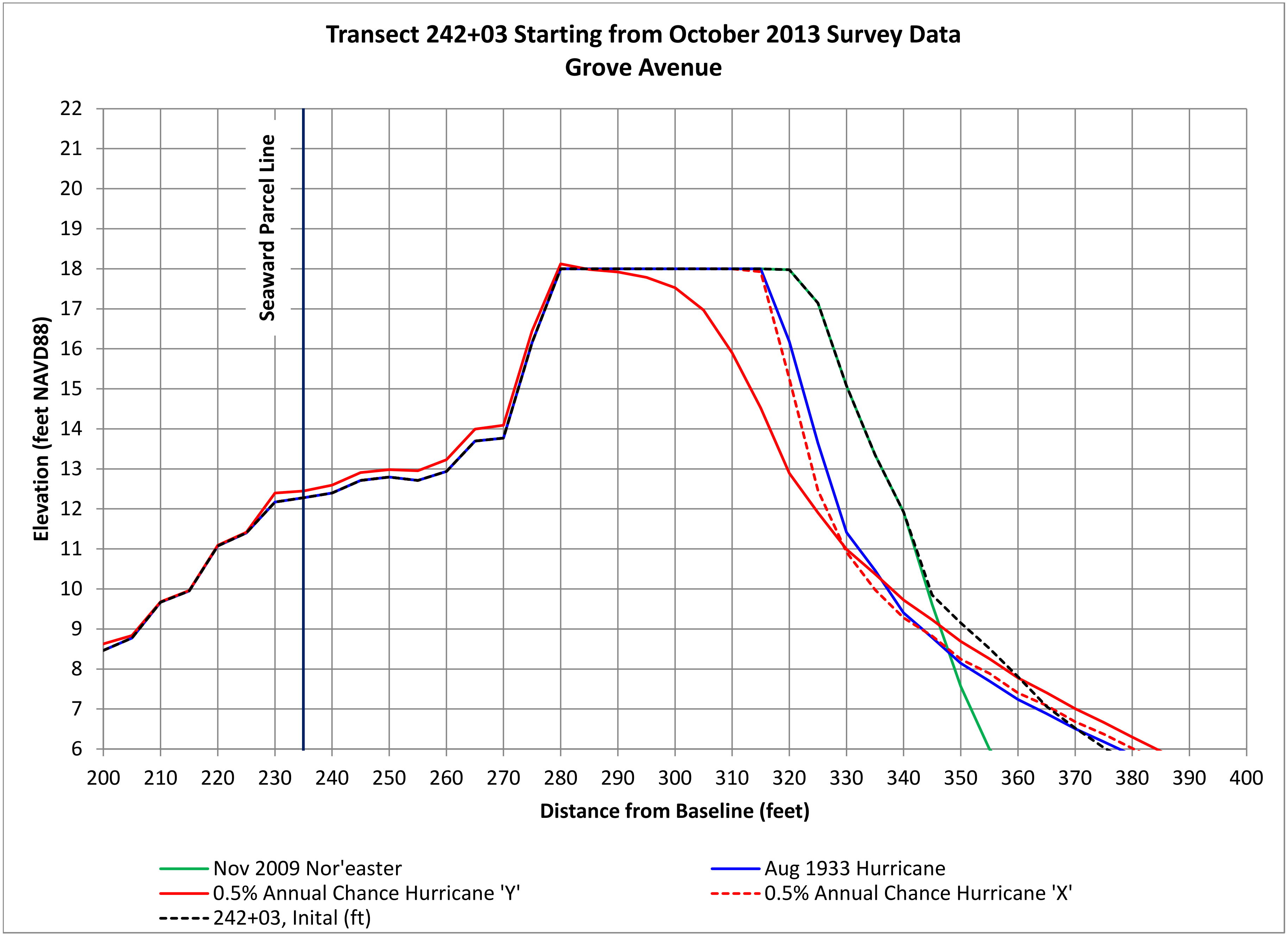

Transect 281+40 Starting from October 2013 Survey Data
3rd Bay Street
Seaward Parcel Line
Elevation (feet NAVD88)
Distance from Baseline (feet)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
430
440
450
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
281+40, Inital (ft)

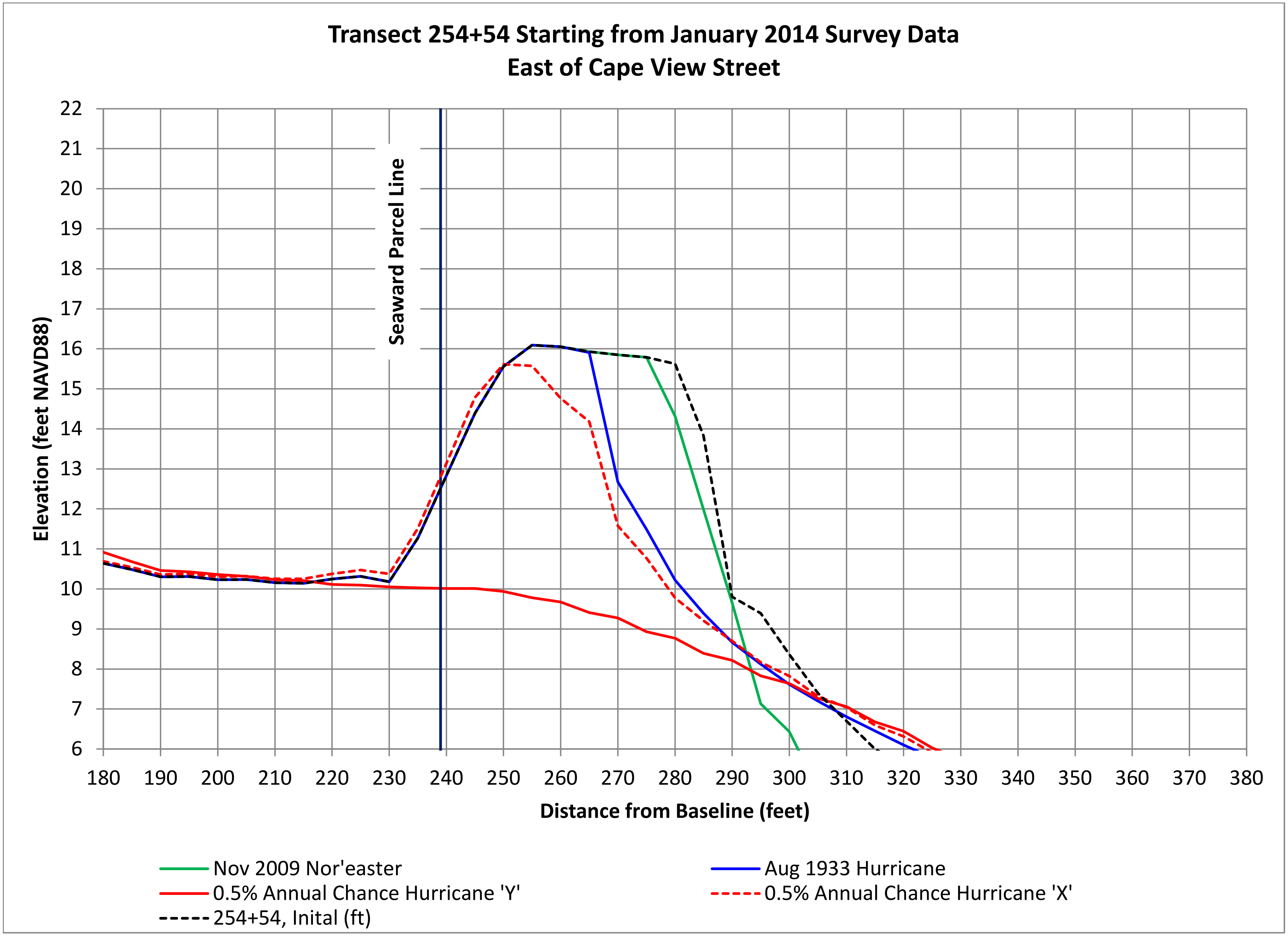
Appendix C: SBEACH Storm Erosion Results, +18 ft NAVD88 Maximum Dune Crest Elevation

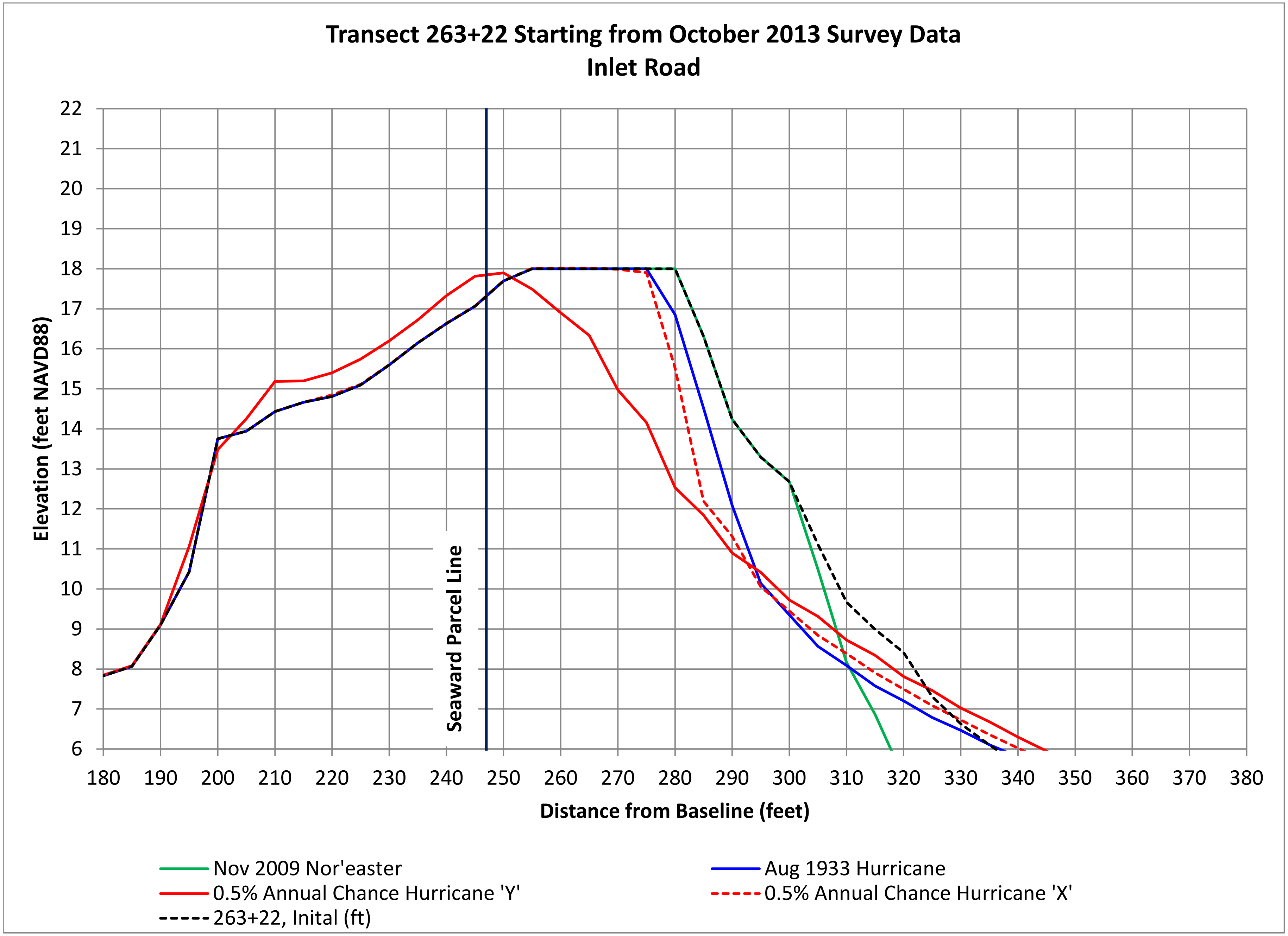

Transect 206+86 Starting from October 2013 Survey Data
Beach View Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
155
165
175
185
195
205
215
225
235
245
255
265
275
285
295
305
315
325
335
345
355
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
206+86, Inital (ft)

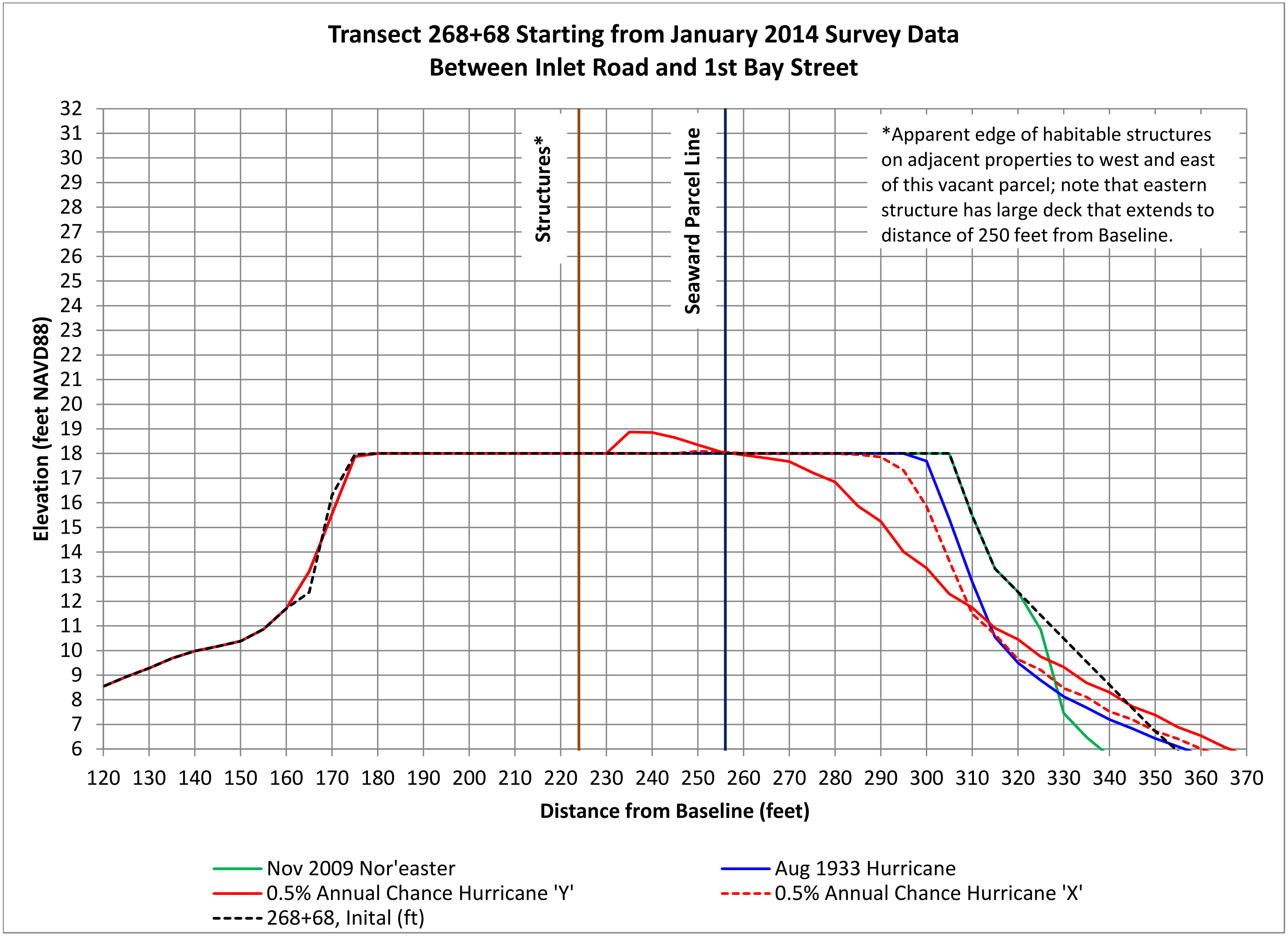

Transect 218+66 Starting from October 2013 Survey Data
Sturgis Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
218+66, Inital (ft)


Transect 229+85 Starting from October 2013 Survey Data
Beaumont Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
430
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
229+85, Inital (ft)

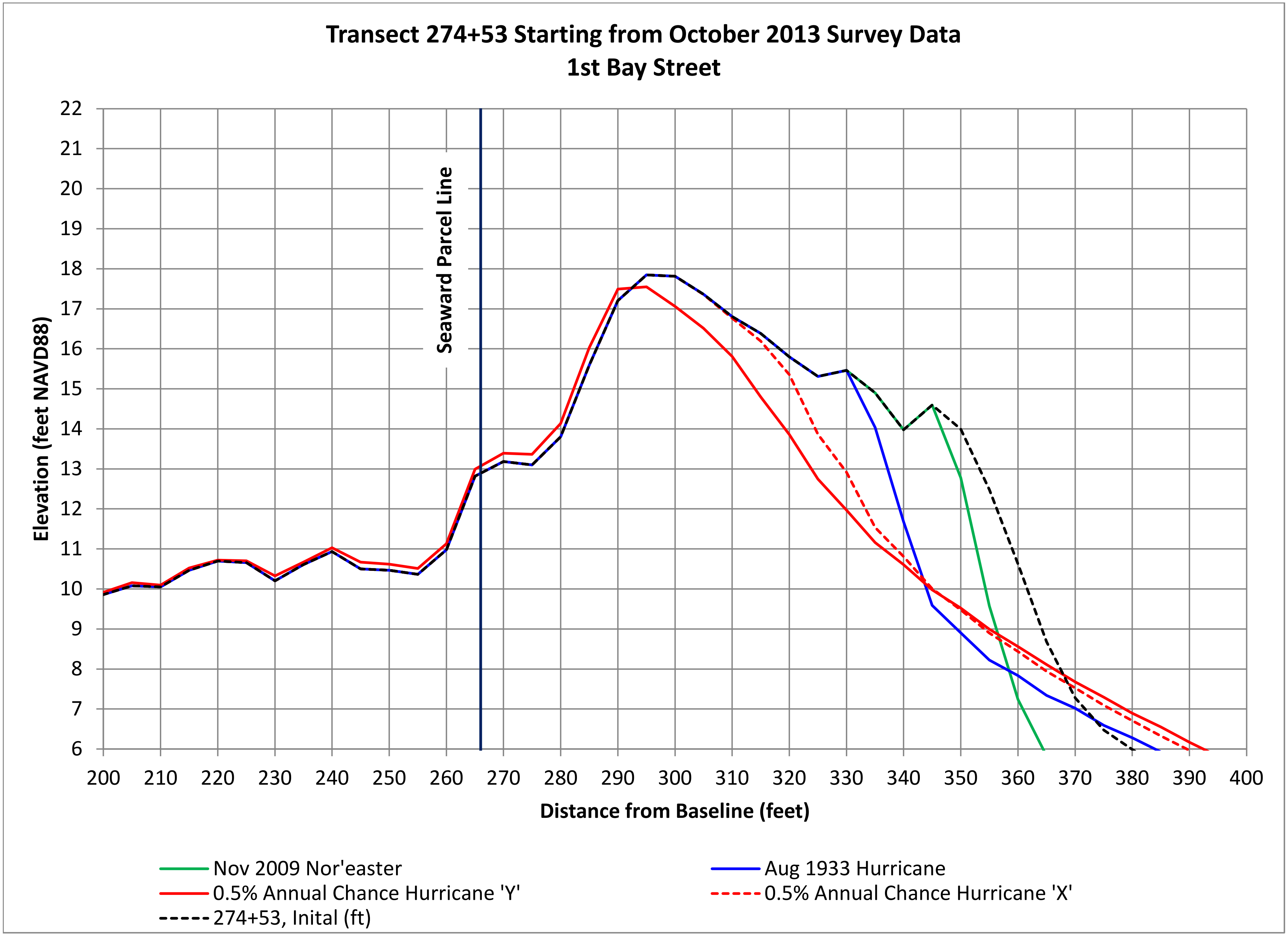

Transect 242+03 Starting from October 2013 Survey Data
Grove Avenue
Elevation (feet NAVD88)
Distance from Baseline (feet)
Seaward Parcel Line
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
242+03, Inital (ft)

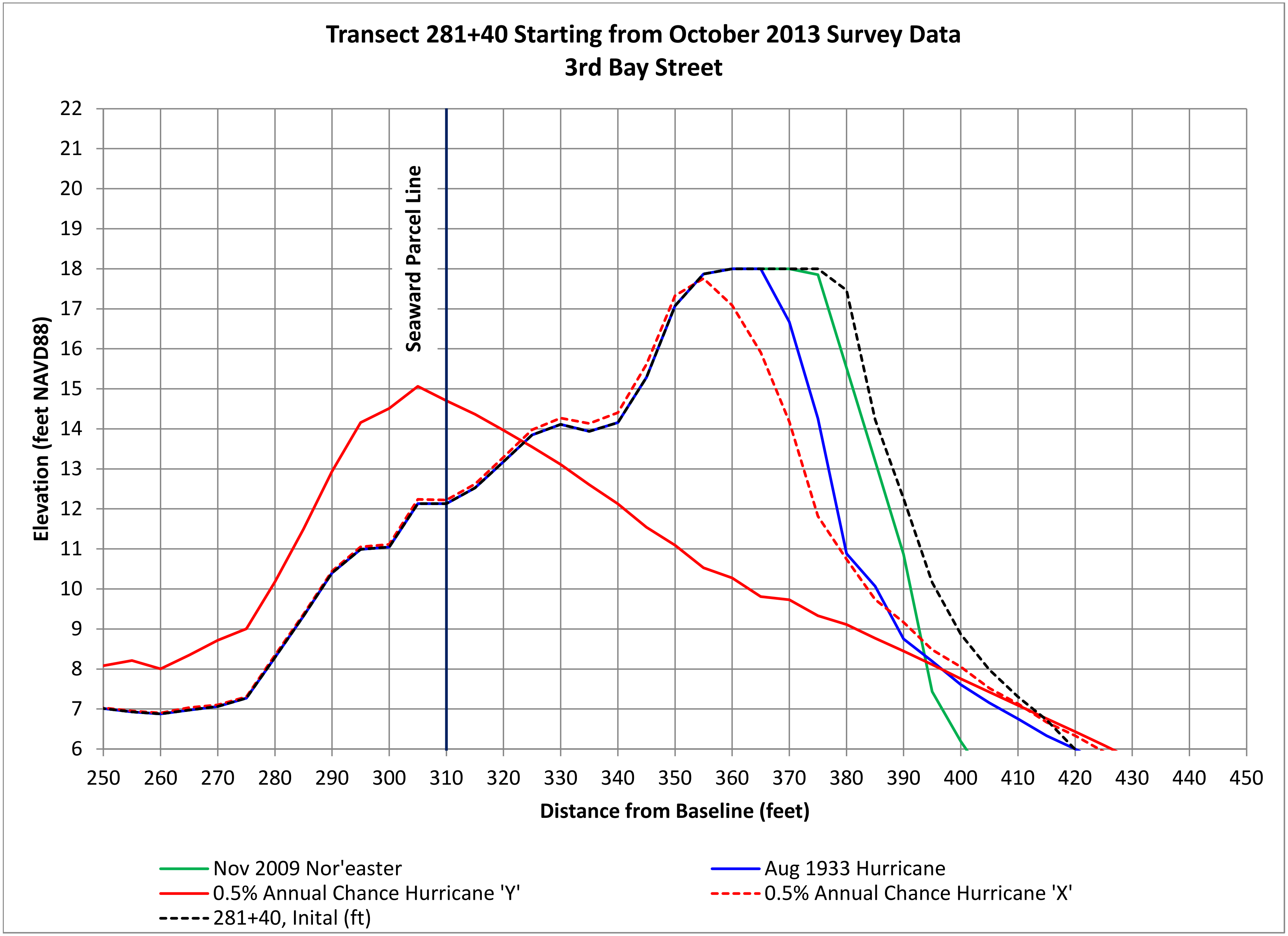

Transect 254+54 Starting from January 2014 Survey Data
East of Cape View Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
254+54, Inital (ft)


Transect 263+22 Starting from October 2013 Survey Data
Inlet Road
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
Seaward Parcel Line
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
263+22, Inital (ft)

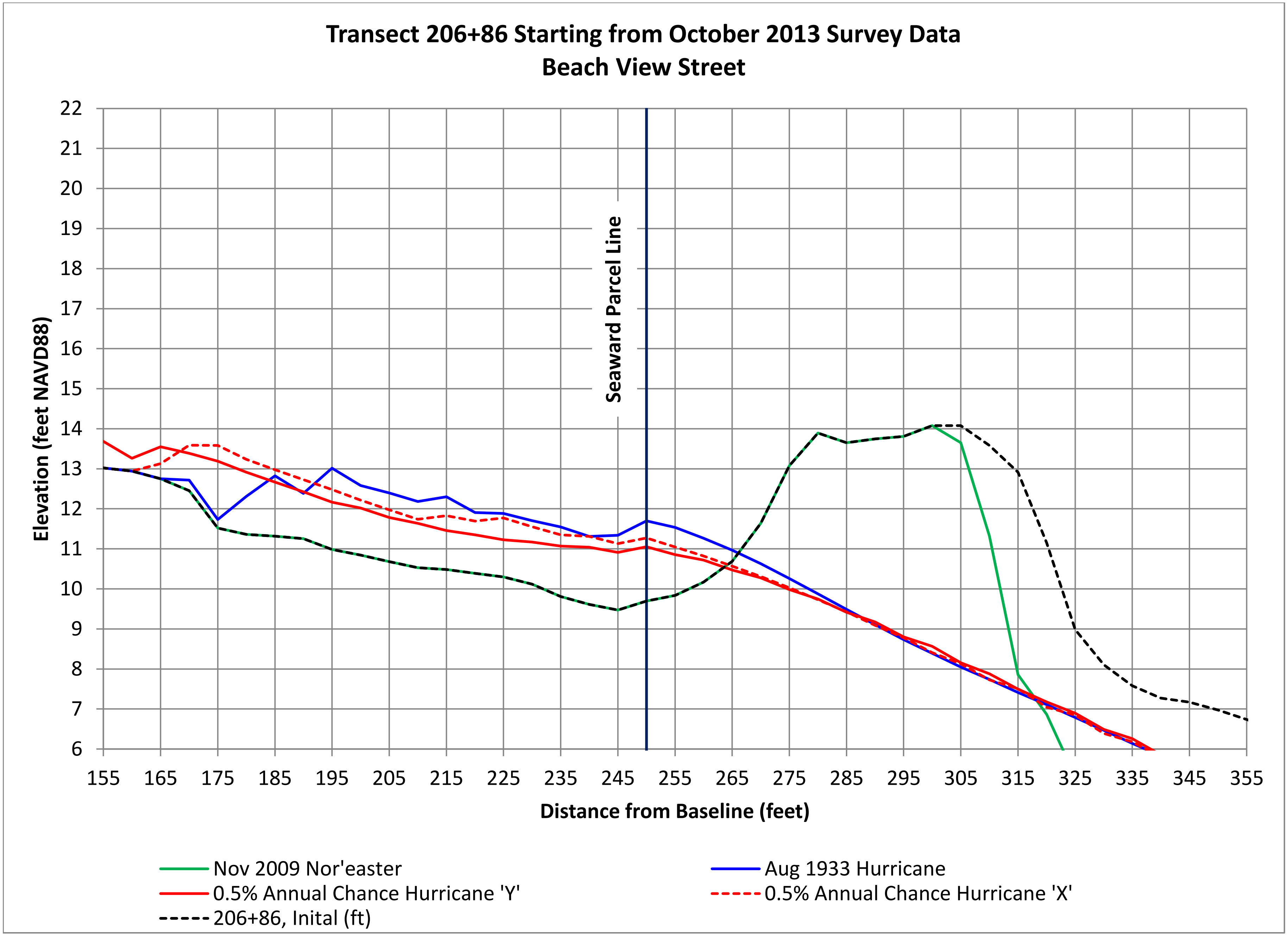

Transect 268+68 Starting from January 2014 Survey Data
Between Inlet Road and 1st Bay Street
Elevation (feet NAVD88)
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
Structures*
Seaward Parcel Line
*Apparent edge of habitable structures on adjacent properties to west and east of this vacant parcel; note that eastern structure has large deck that extends to distance of 250 feet from Baseline.
120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360 370
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
268+68, Inital (ft)

moffatt & nichol

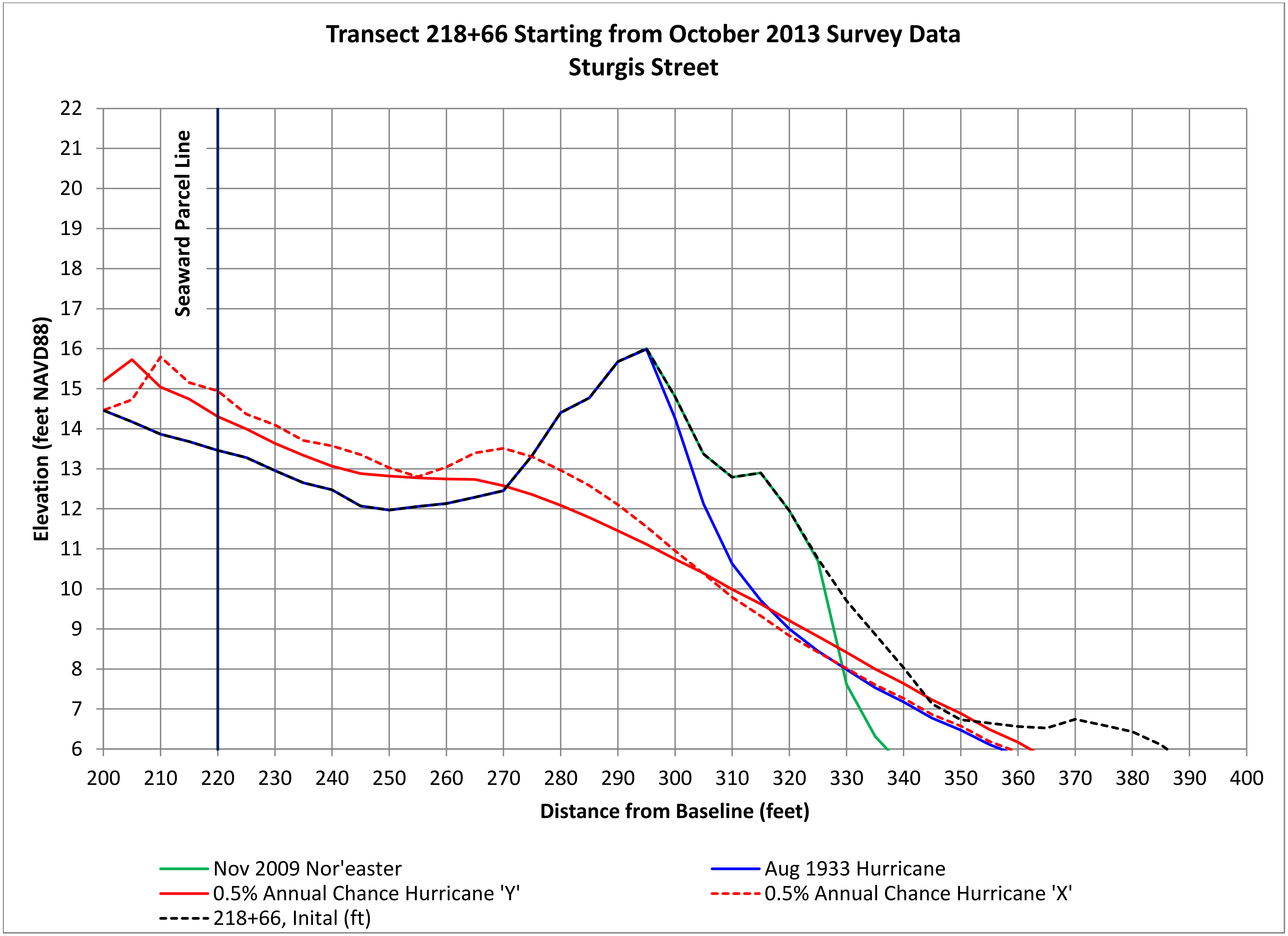



Transect 281+40 Starting from October 2013 Survey Data
3rd Bay Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
430
440
450
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
281+40, Inital (ft)

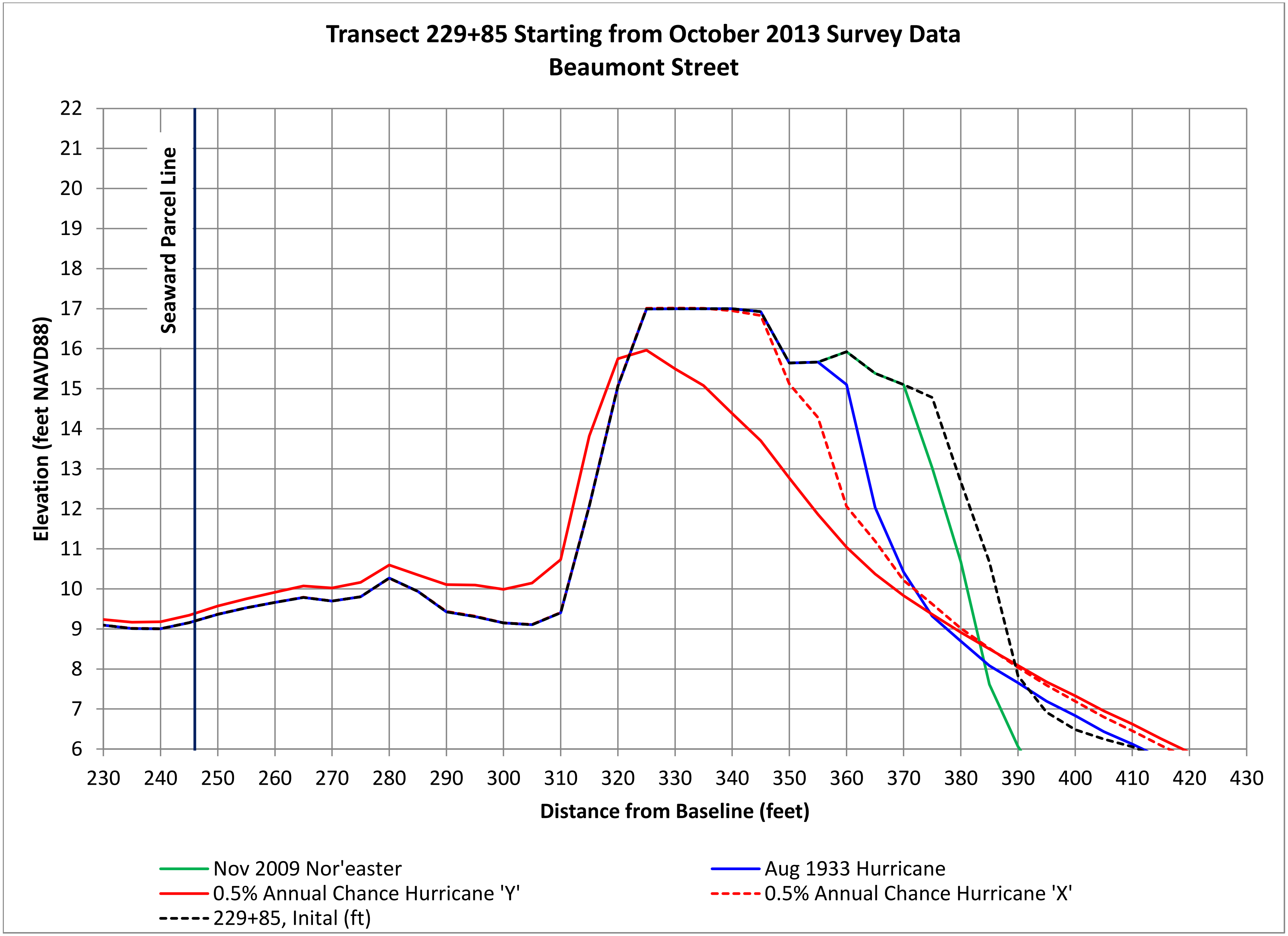
Appendix D: SBEACH Storm Erosion Results, +17 ft NAVD88 Maximum Dune Crest Elevation

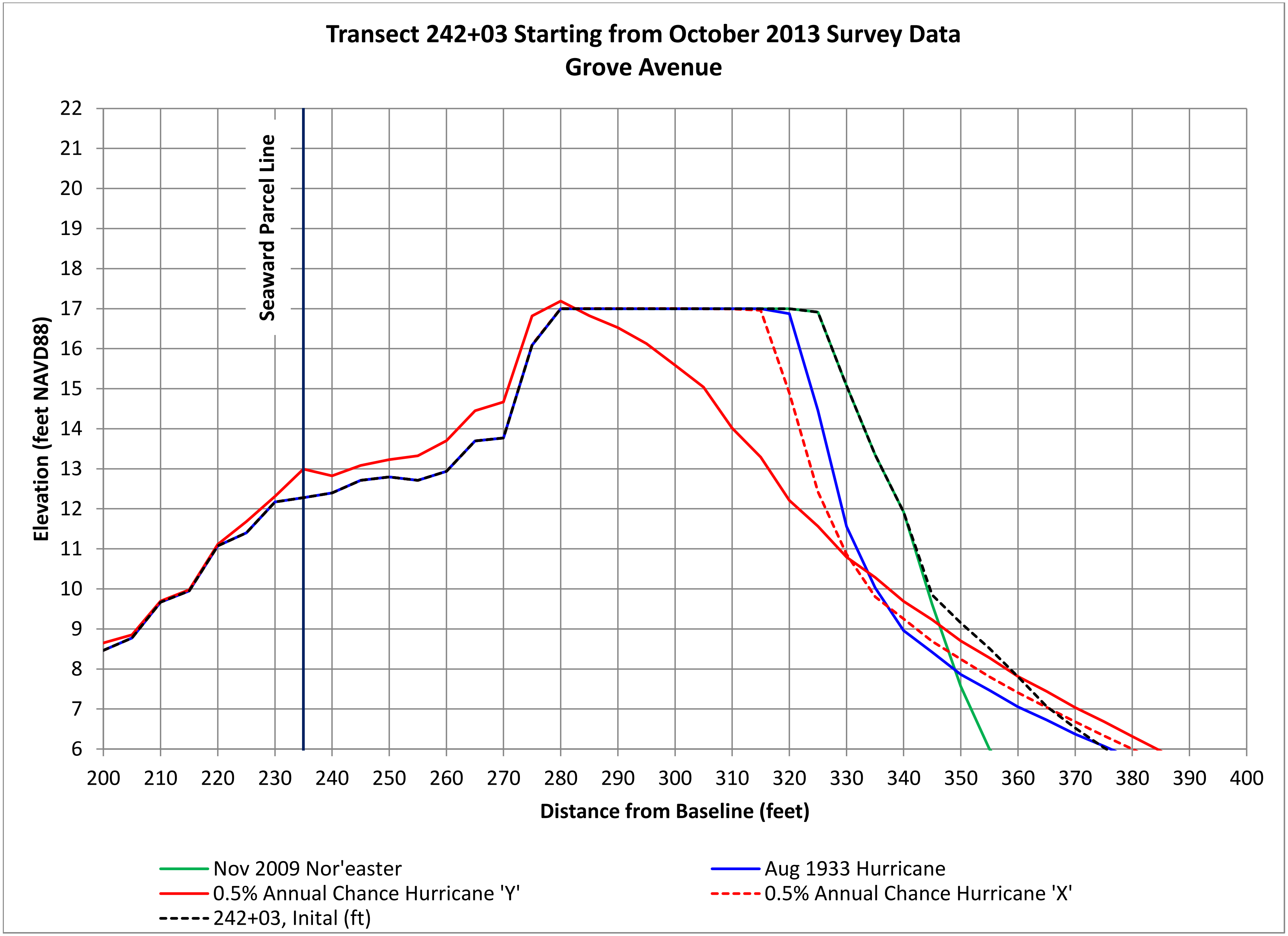


Transect 206+86 Starting from October 2013 Survey Data
Beach View Street
Seaward Parcel Line
Elevation (feet NAVD88)
Distance from Baseline (feet)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
155
165
175
185
195
205
215
225
235
245
255
265
275
285
295
305
315
325
335
345
355
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
206+86, Inital (ft)

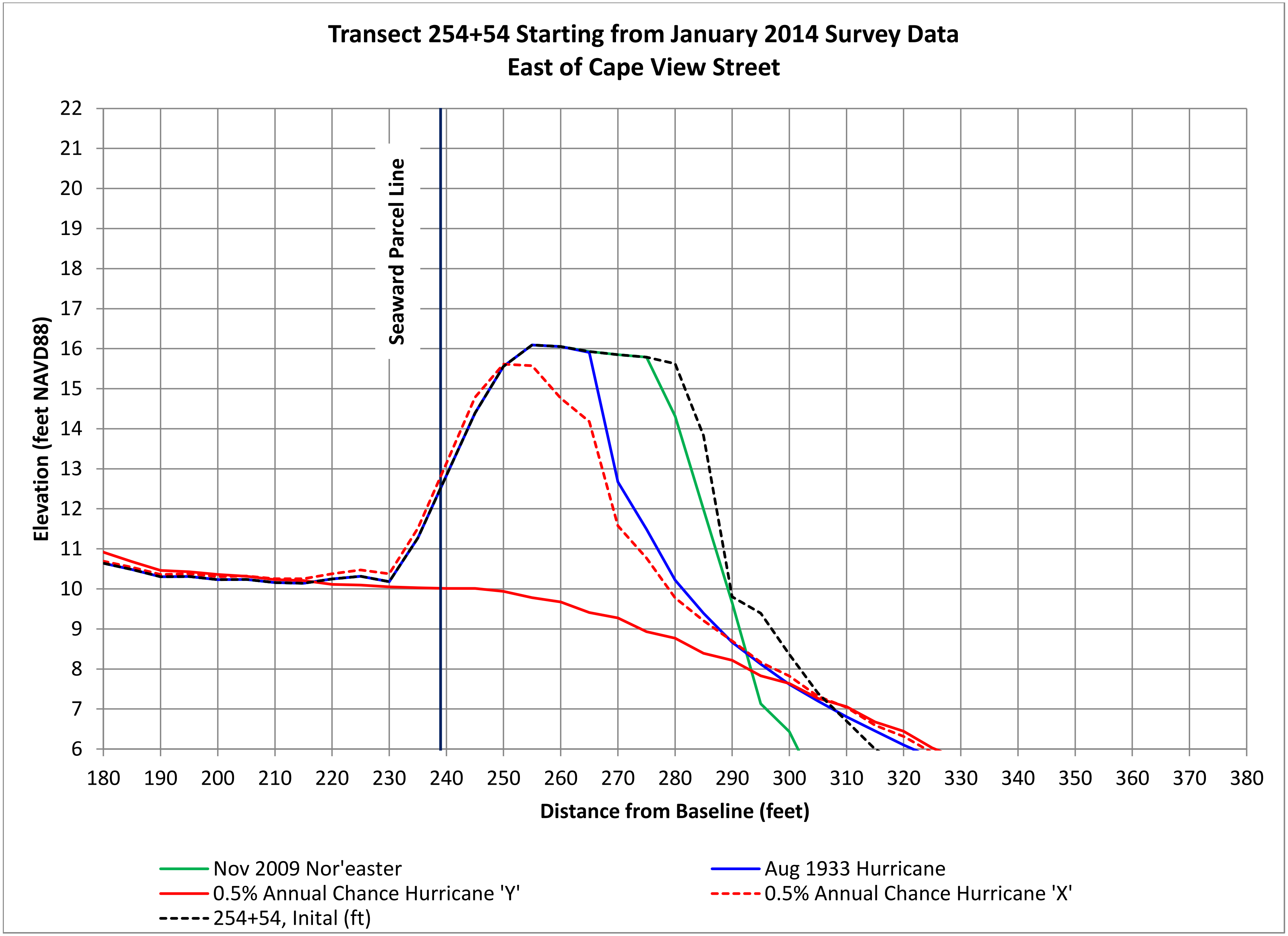


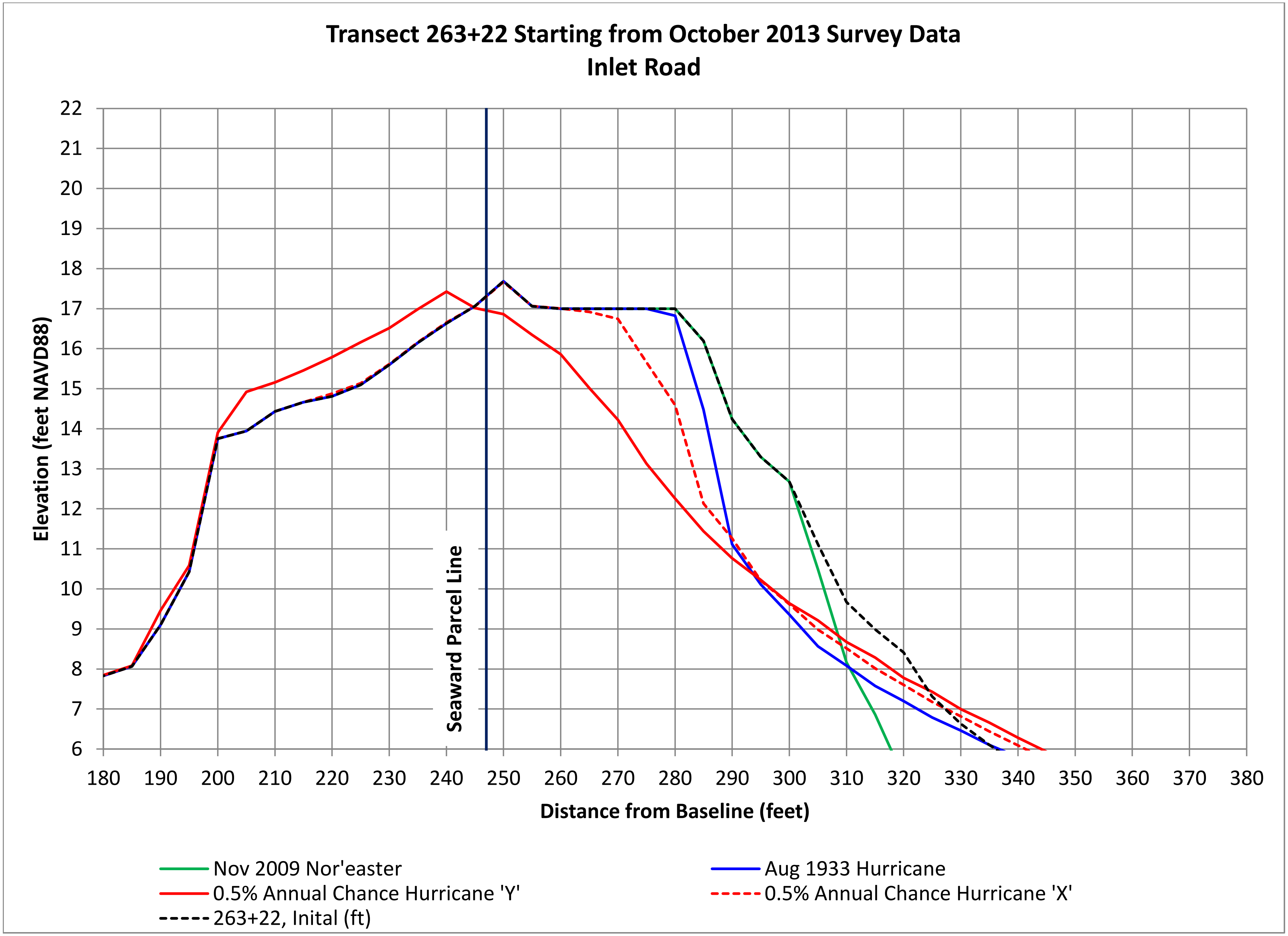
Transect 218+66 Starting from October 2013 Survey Data
Sturgis Street
Seaward Parcel Line
Elevation (feet NAVD88)
Distance from Baseline (feet)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
218+66, Inital (ft)

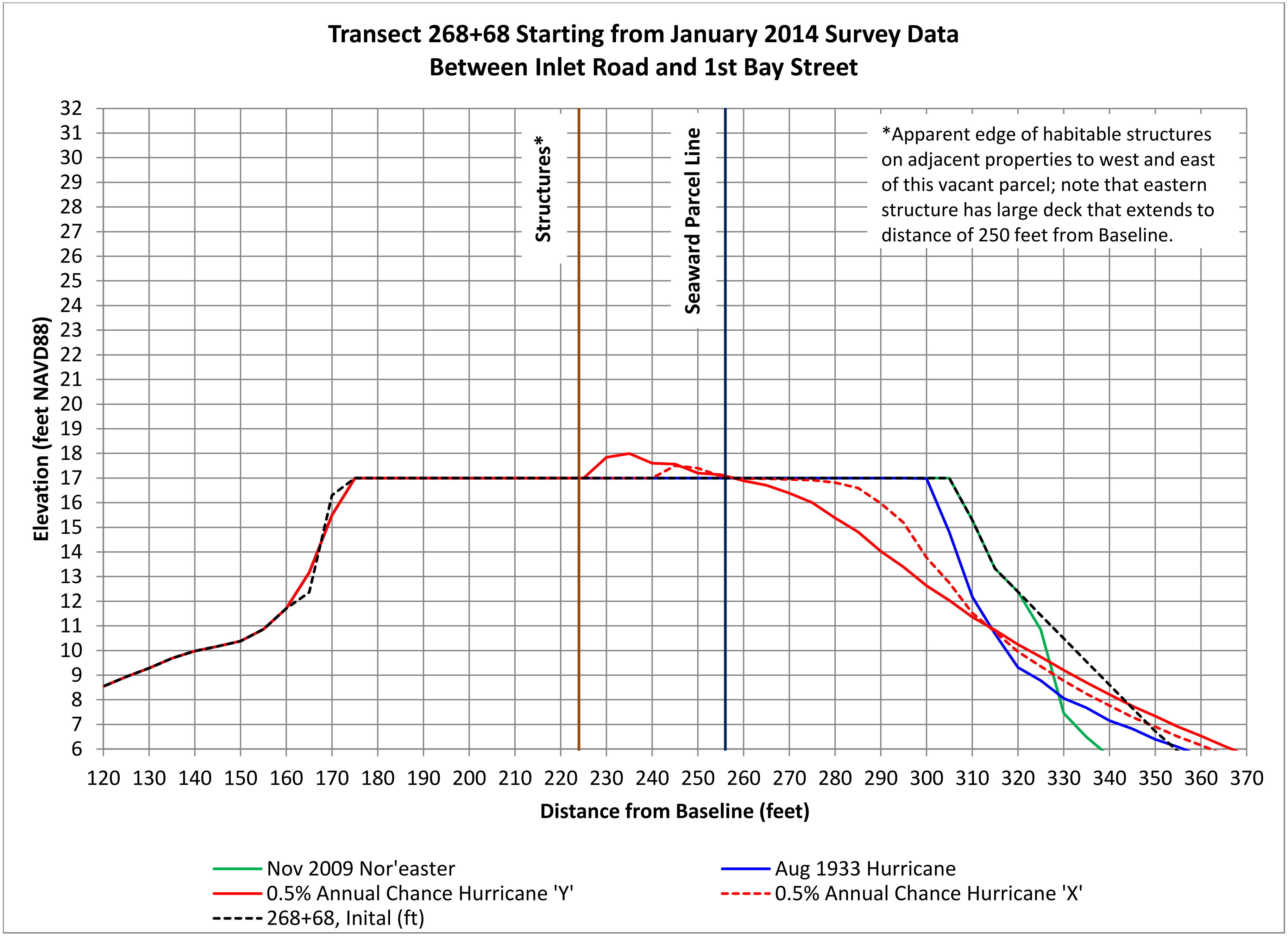

Transect 229+85 Starting from October 2013 Survey Data
Beaumont Street
Seaward Parcel Line
Elevation (feet NAVD88)
Distance from Baseline (feet)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
430
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
229+85, Inital (ft)

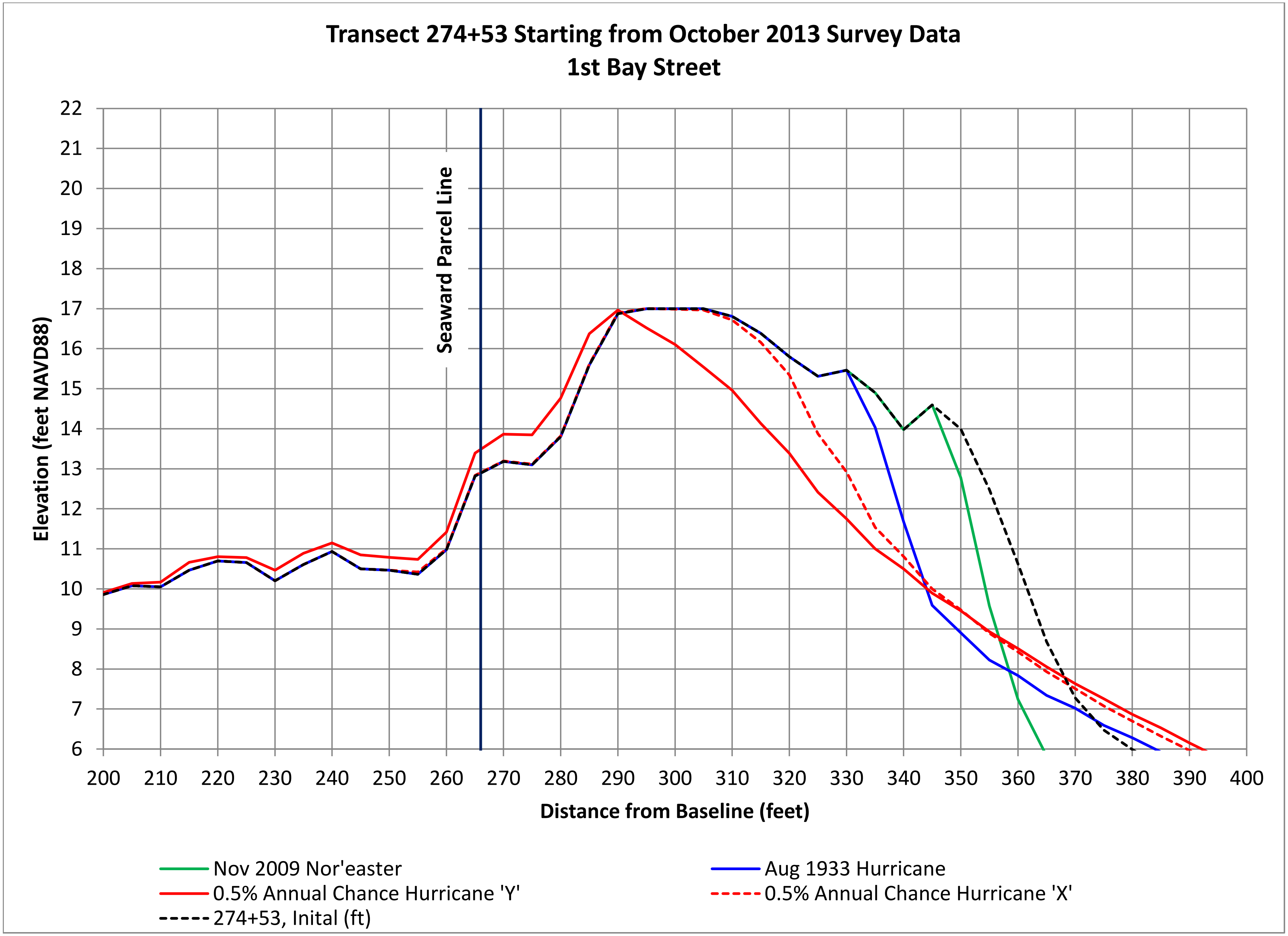


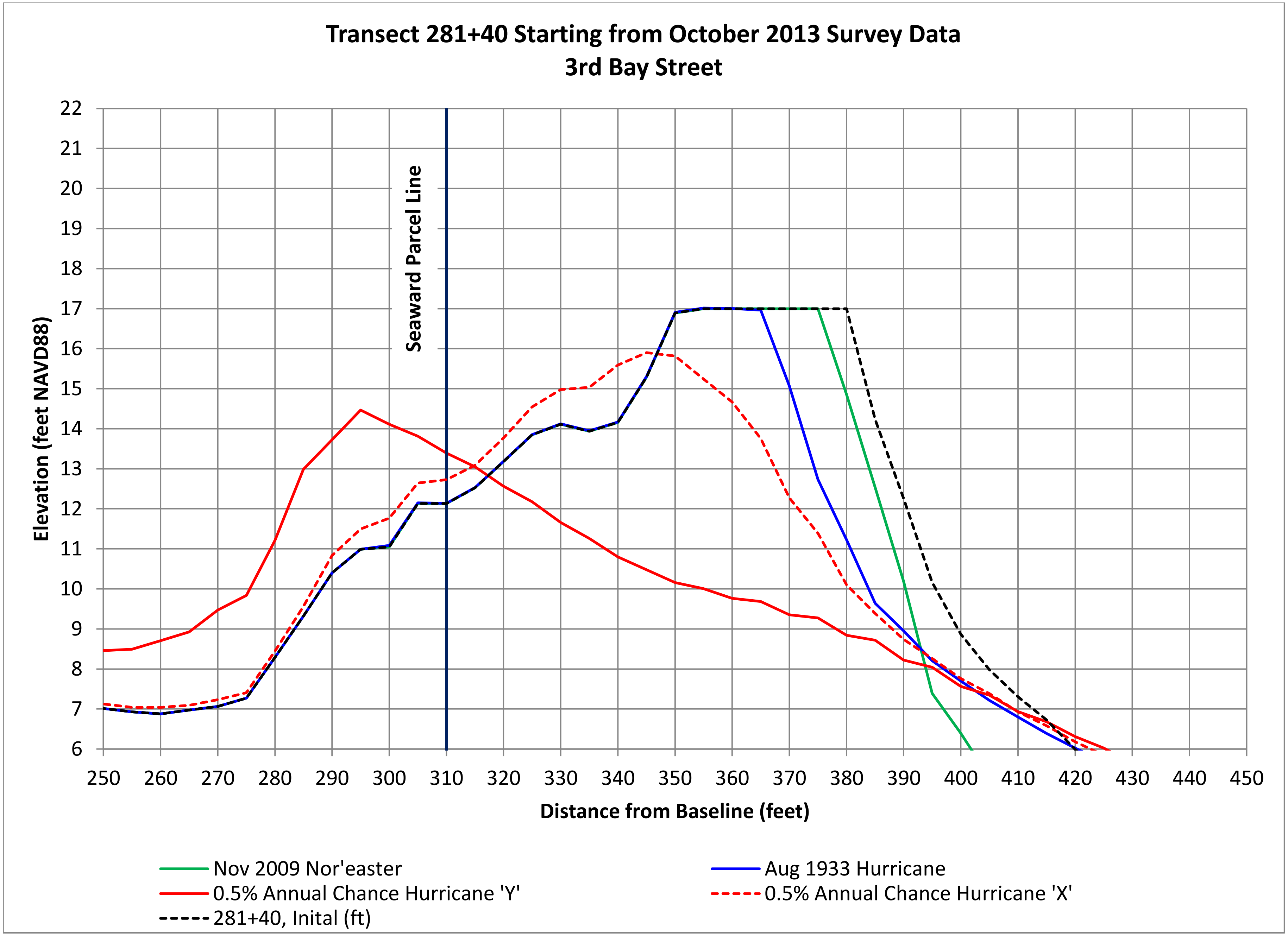
Transect 242+03 Starting from October 2013 Survey Data
Grove Avenue
Seaward Parcel Line
Elevation (feet NAVD88)
Distance from Baseline (feet)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
242+03, Inital (ft)


Transect 254+54 Starting from January 2014 Survey Data
East of Cape View Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360 370 380
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
254+54, Inital (ft)

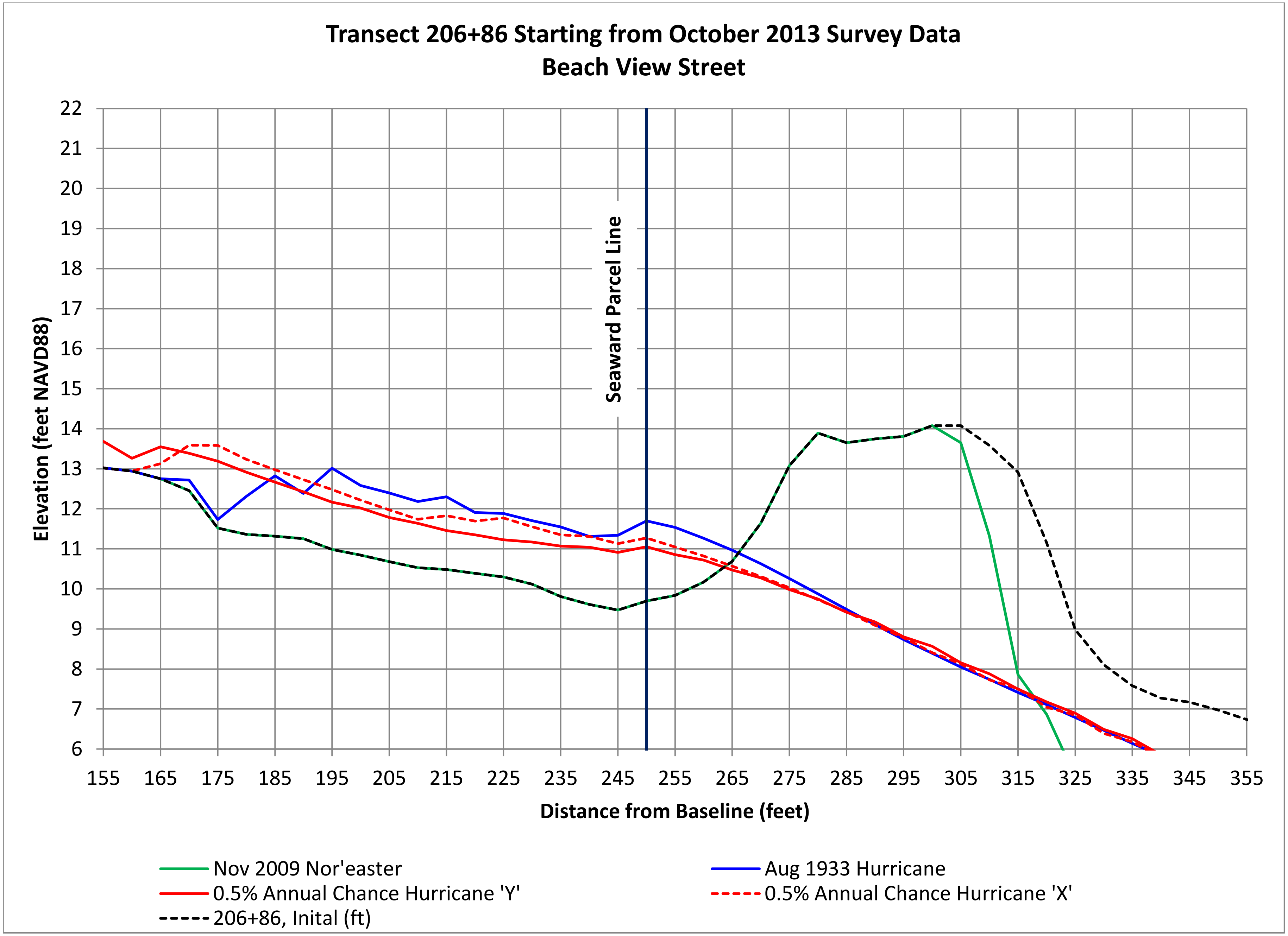

Transect 263+22 Starting from October 2013 Survey Data
Inlet Road
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
Seaward Parcel Line
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
263+22, Inital (ft)

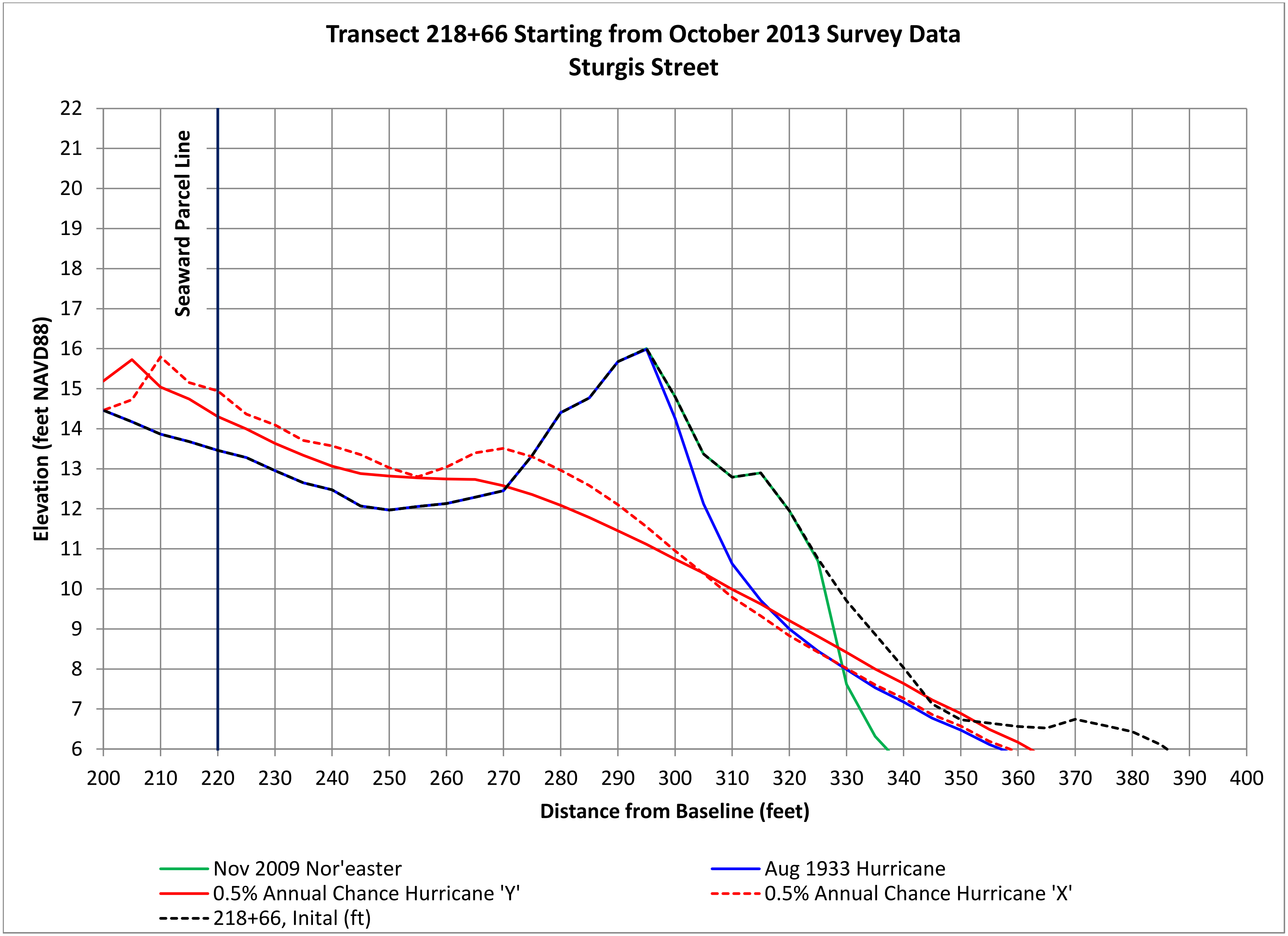

Transect 268+68 Starting from January 2014 Survey Data
Between Inlet Road and 1st Bay Street
Structures*
Seaward Parcel Line
*Apparent edge of habitable structures on adjacent properties to west and east of this vacant parcel; note that eastern structure has large deck that extends to distance of 250 feet from Baseline.
Elevation (feet NAVD88)
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
268+68, Inital (ft)

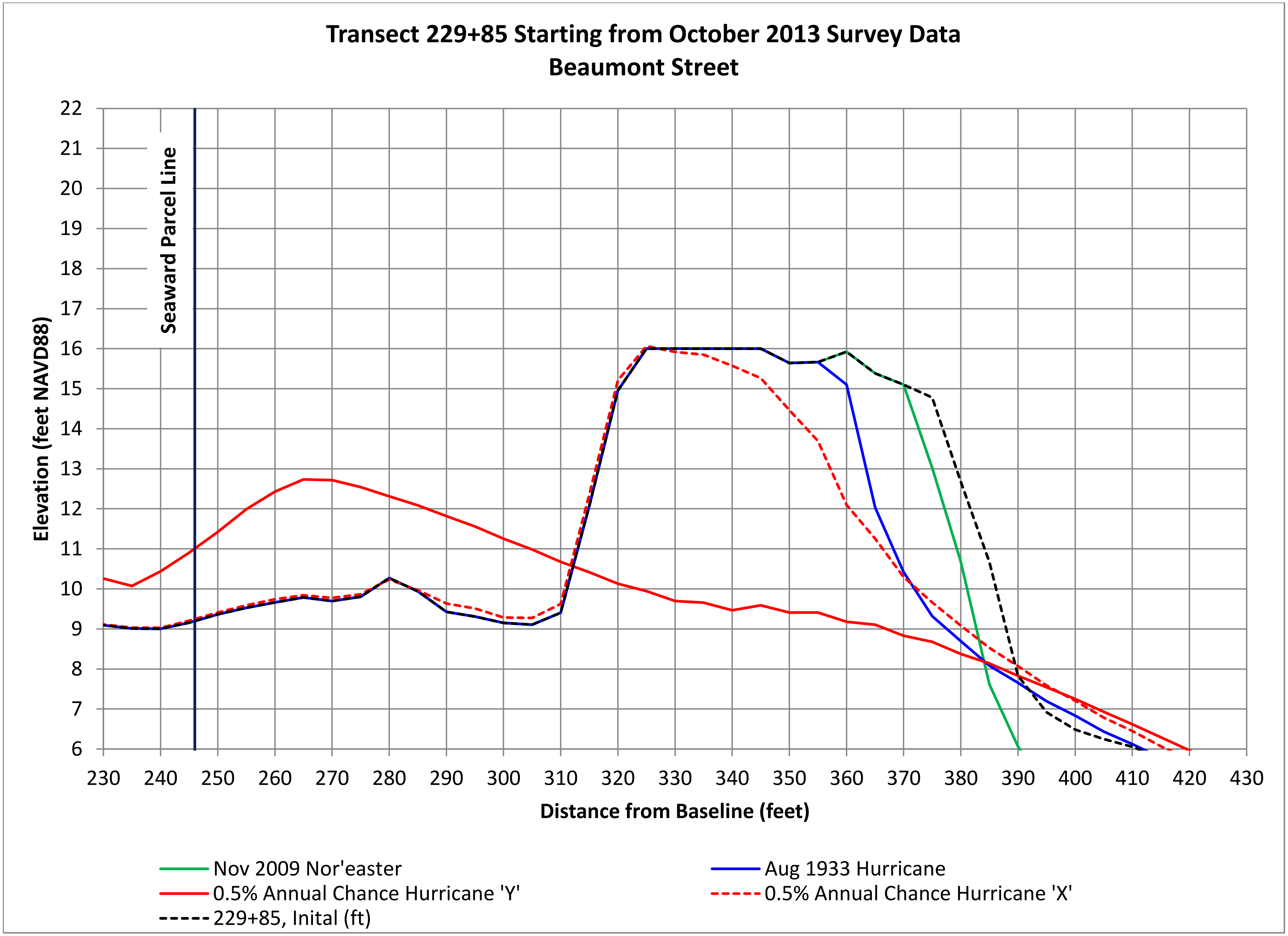

Transect 274+53 Starting from October 2013 Survey Data
1st Bay Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
274+53, Inital (ft)


Transect 281+40 Starting from October 2013 Survey Data
3rd Bay Street
Seaward Parcel Line
Elevation (feet NAVD88)
Distance from Baseline (feet)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
250 260 270 280 290 300 310 320 330 340 350 360 370 380 390 400 410 420 430 440 450
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
281+40, Inital (ft)

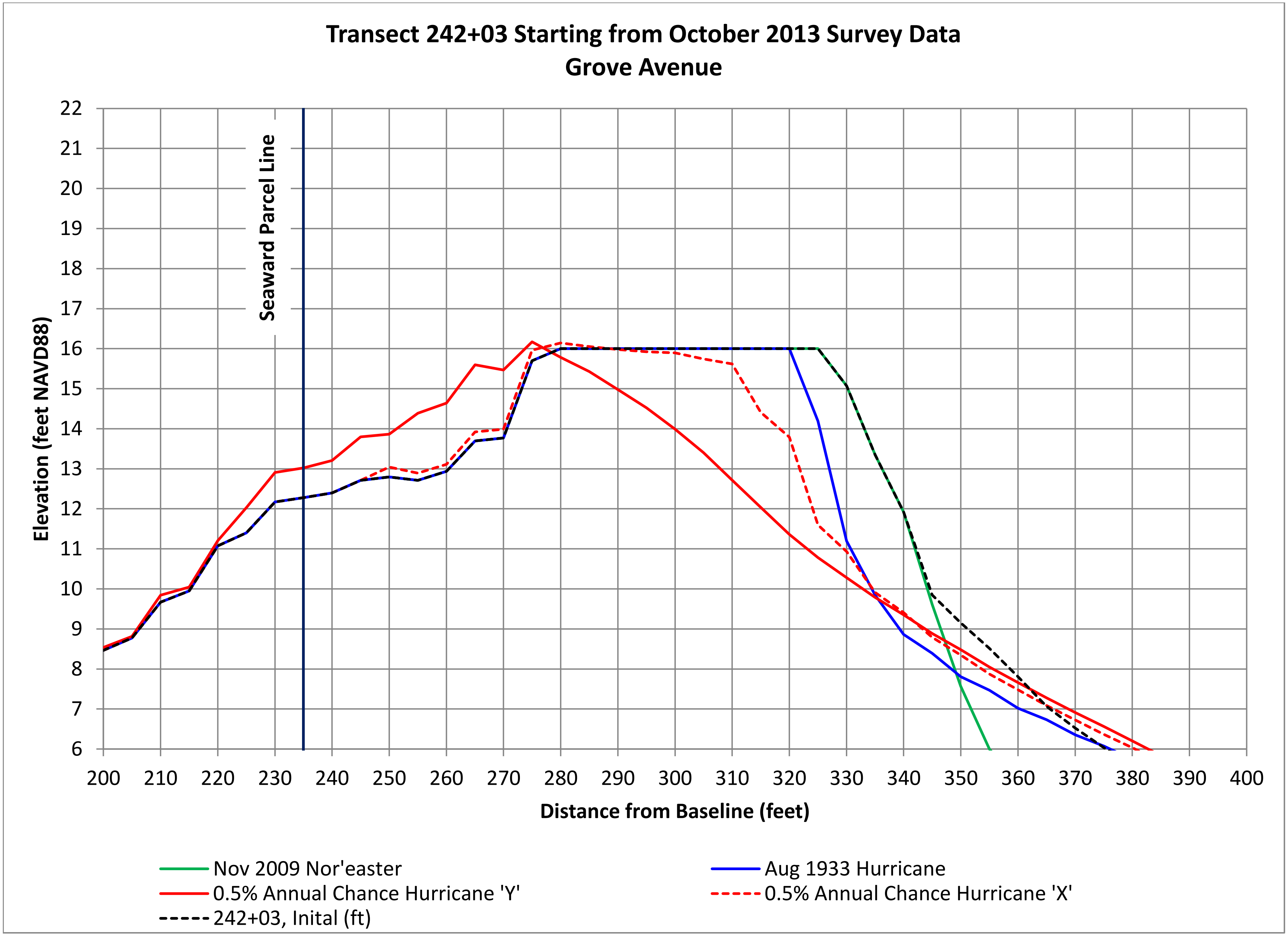
Appendix E: SBEACH Storm Erosion Results, +16 ft NAVD88 Maximum Dune Crest Elevation

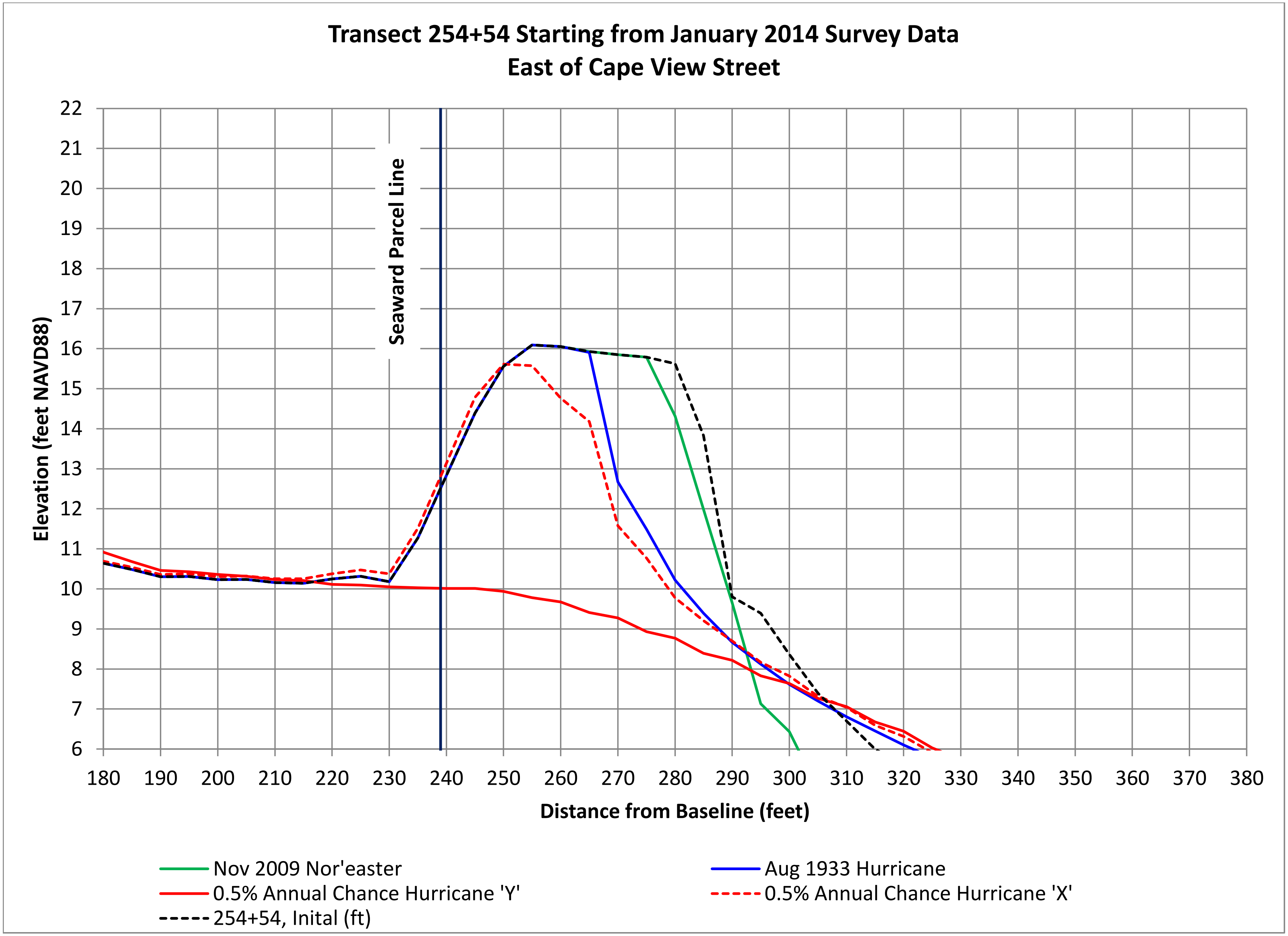

Transect 206+86 Starting from October 2013 Survey Data
Beach View Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
155
165
175
185
195
205
215
225
235
245
255
265
275
285
295
305
315
325
335
345
355
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
206+86, Inital (ft)

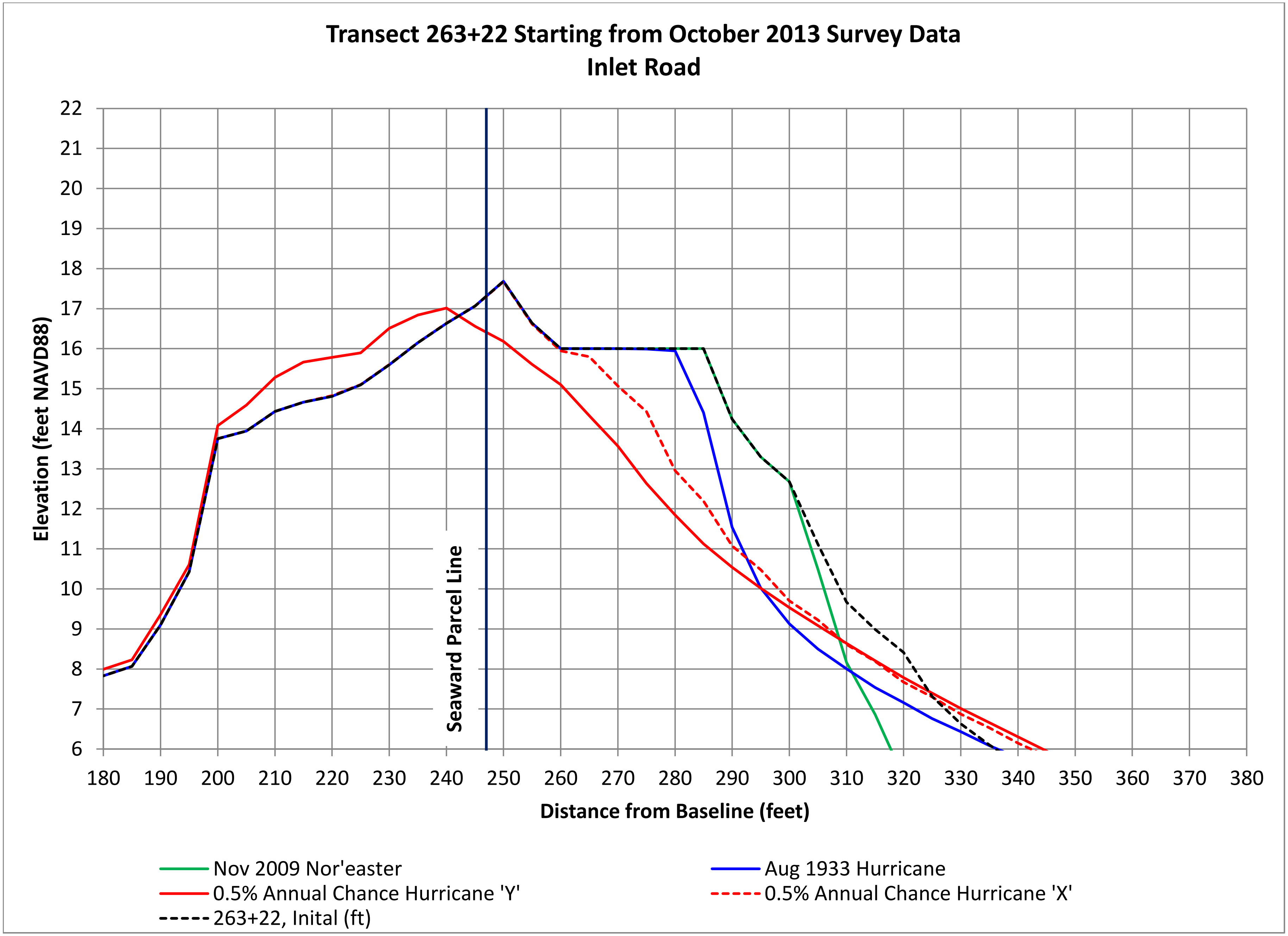

Transect 218+66 Starting from October 2013 Survey Data
Sturgis Street
Seaward Parcel Line
Elevation (feet NAVD88)
Distance from Baseline (feet)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
218+66, Inital (ft)



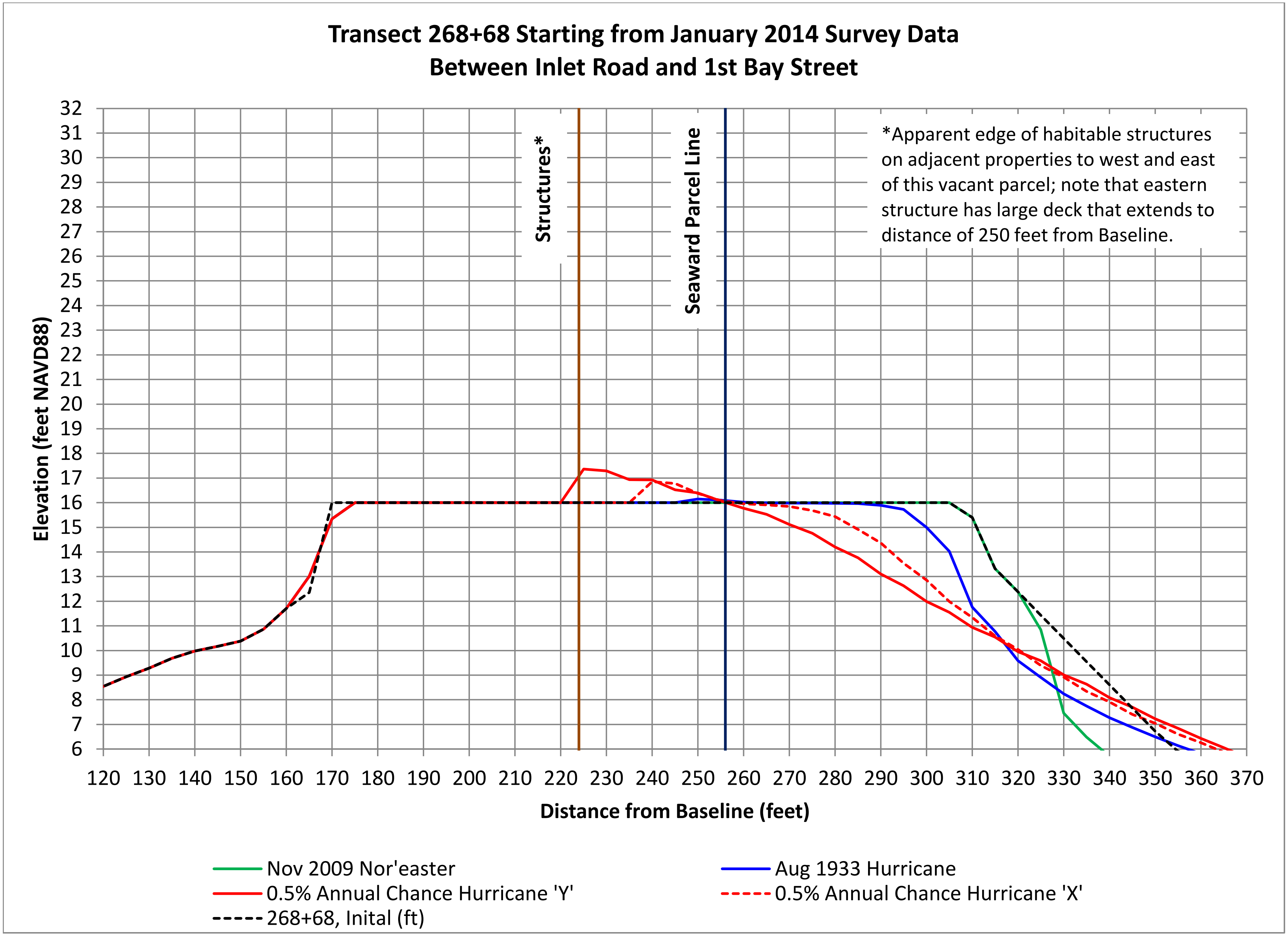
Transect 229+85 Starting from October 2013 Survey Data
Beaumont Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
430
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
229+85, Inital (ft)

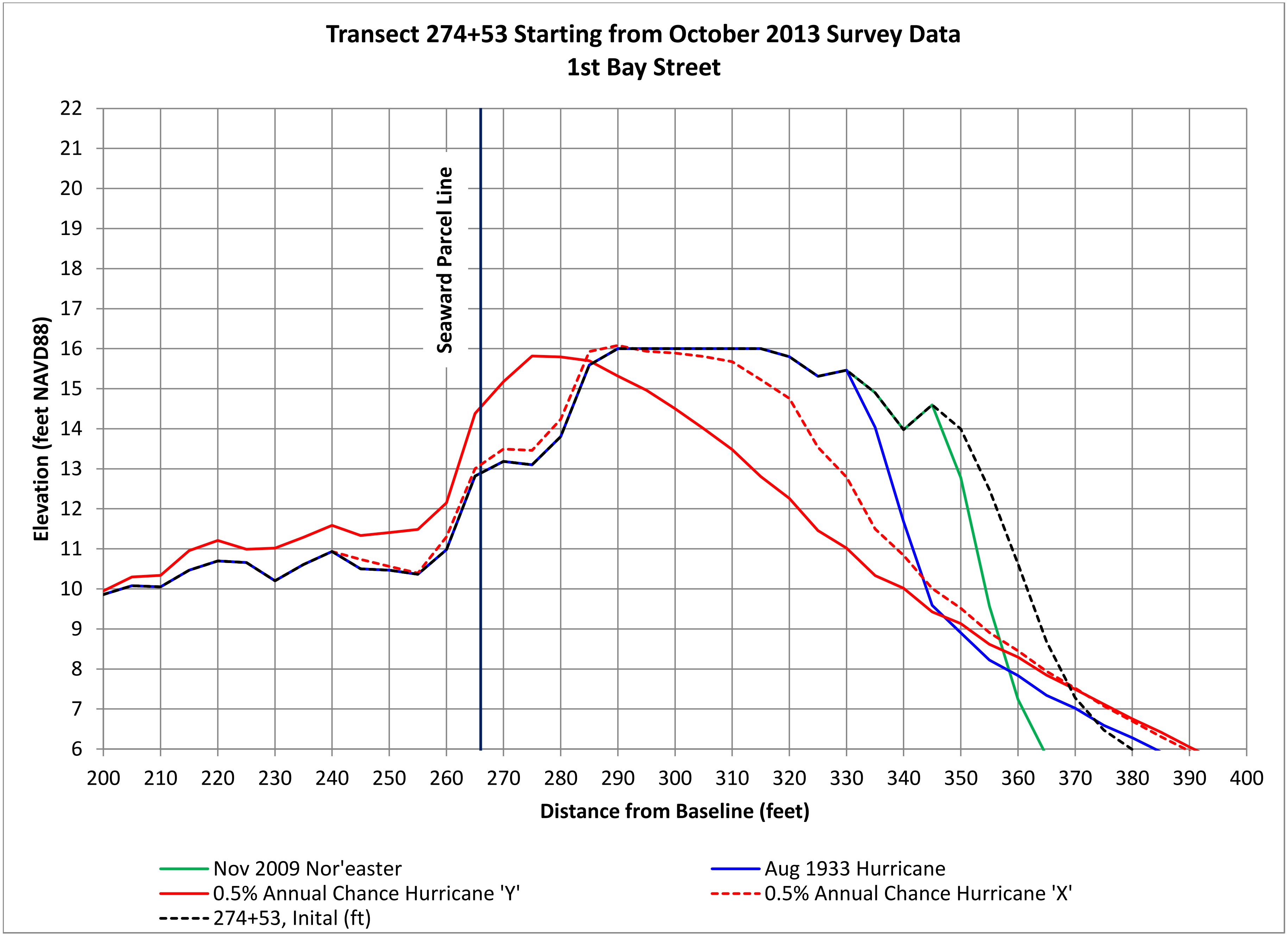

Transect 242+03 Starting from October 2013 Survey Data
Grove Avenue
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
242+03, Inital (ft)


Transect 254+54 Starting from January 2014 Survey Data
East of Cape View Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
254+54, Inital (ft)

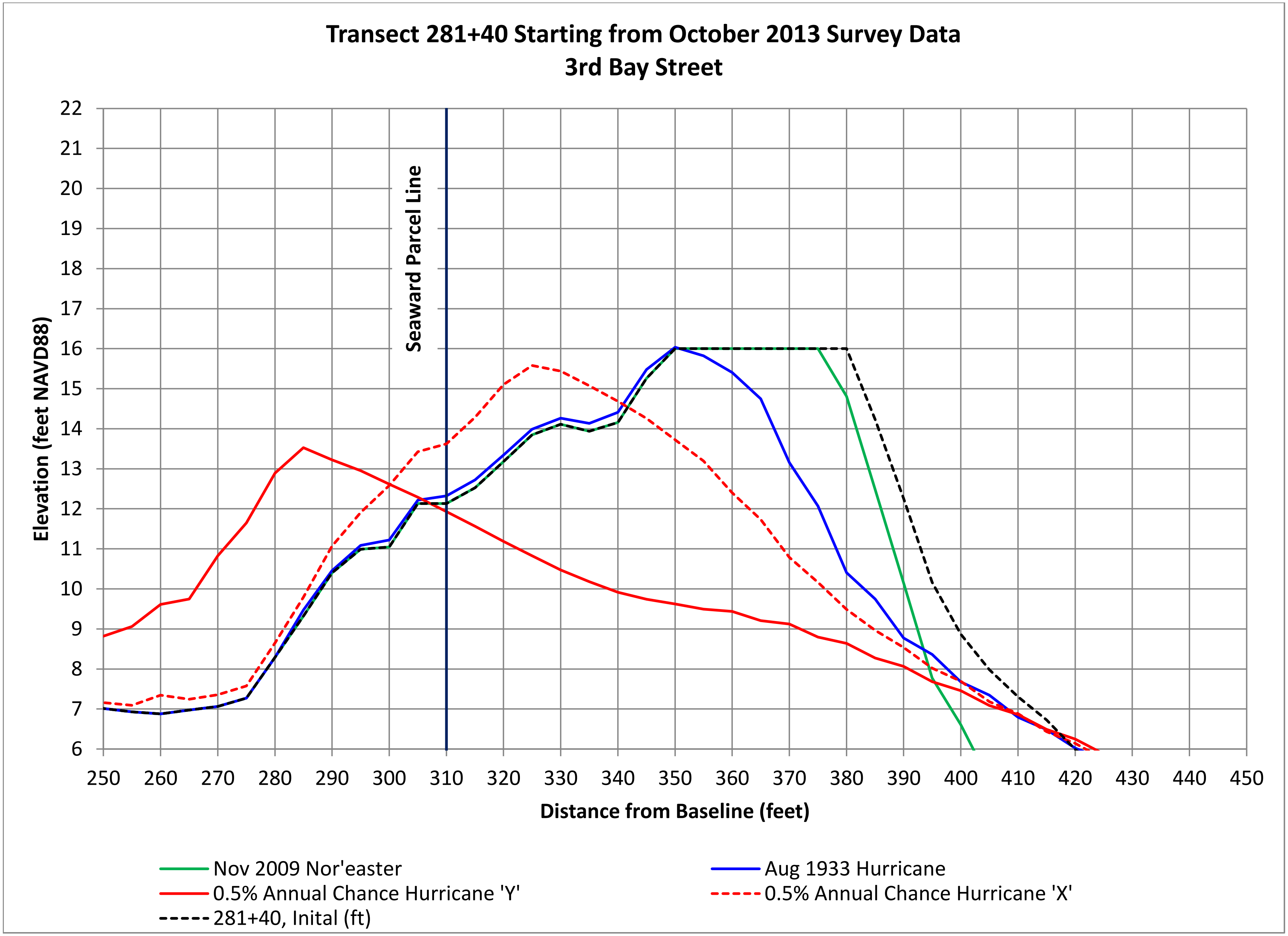


Transect 263+22 Starting from October 2013 Survey Data
Inlet Road
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
Seaward Parcel Line
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
263+22, Inital (ft)

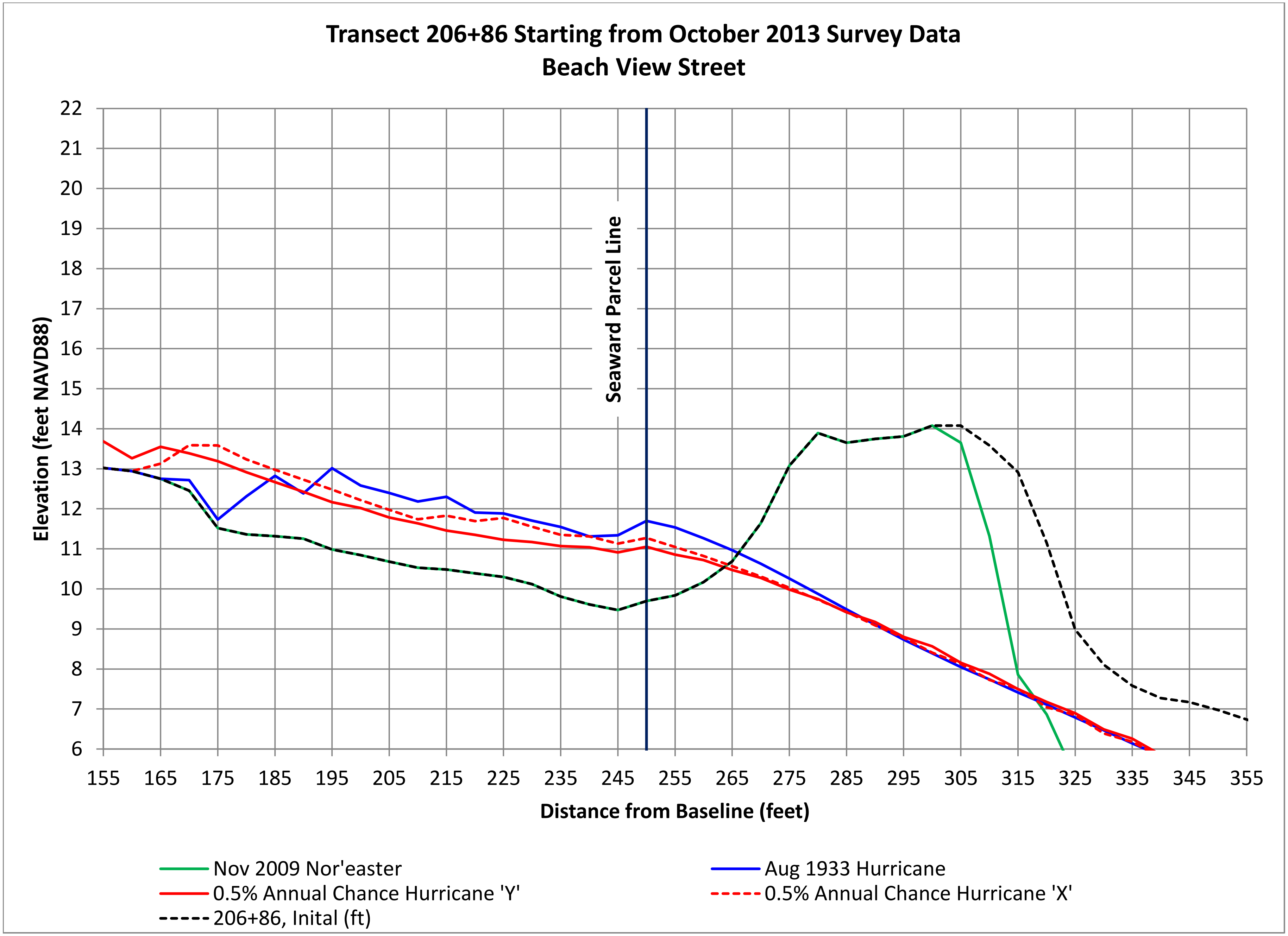

Transect 268+68 Starting from January 2014 Survey Data
Between Inlet Road and 1st Bay Street
Structures*
Seaward Parcel Line
*Apparent edge of habitable structures on adjacent properties to west and east of this vacant parcel; note that eastern structure has large deck that extends to distance of 250 feet from Baseline.
Elevation (feet NAVD88)
Distance from Baseline (feet)
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360 370
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
268+68, Inital (ft)

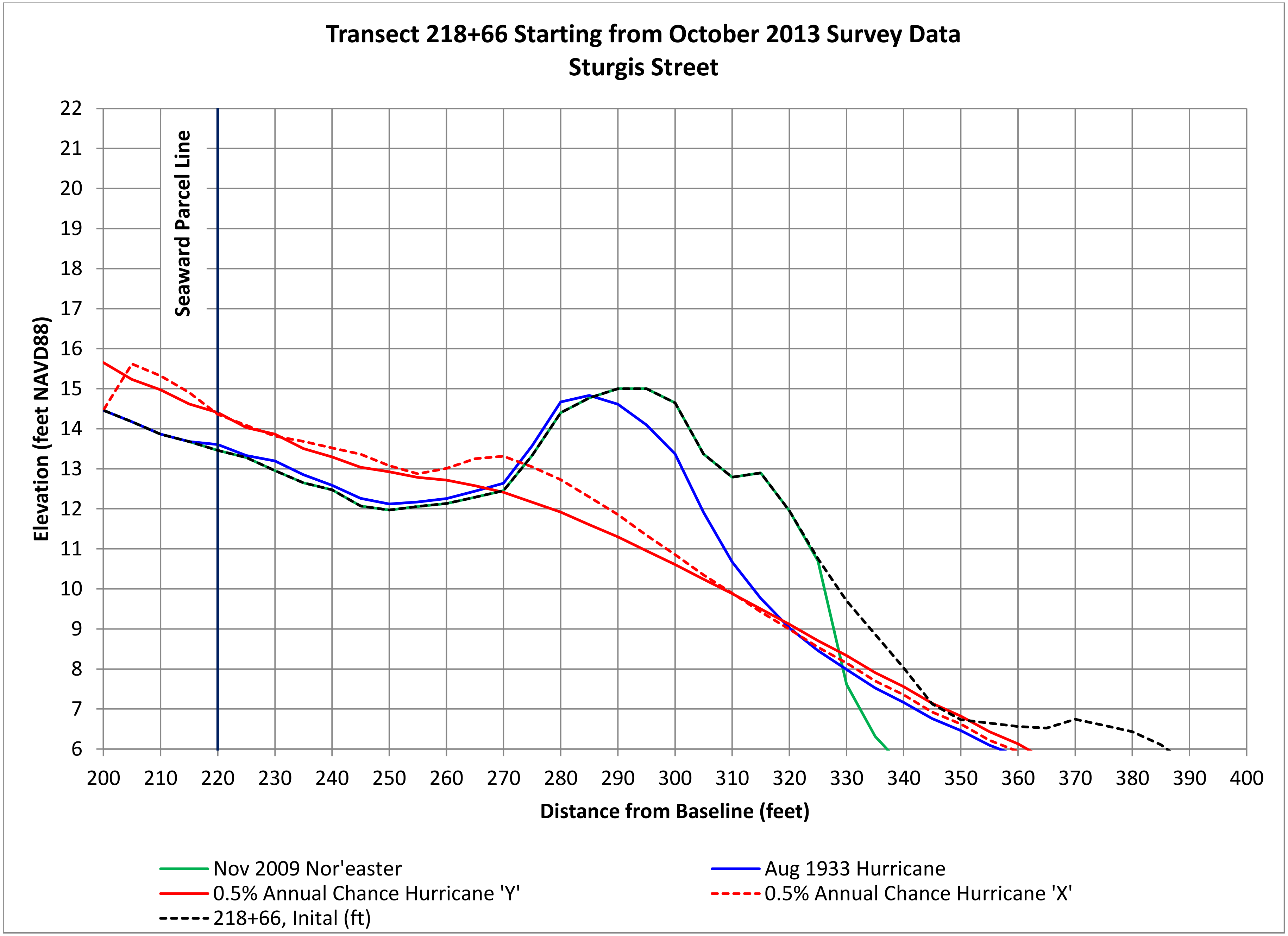


Transect 274+53 Starting from October 2013 Survey Data
1st Bay Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360 370 380 390 400
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
274+53, Inital (ft)

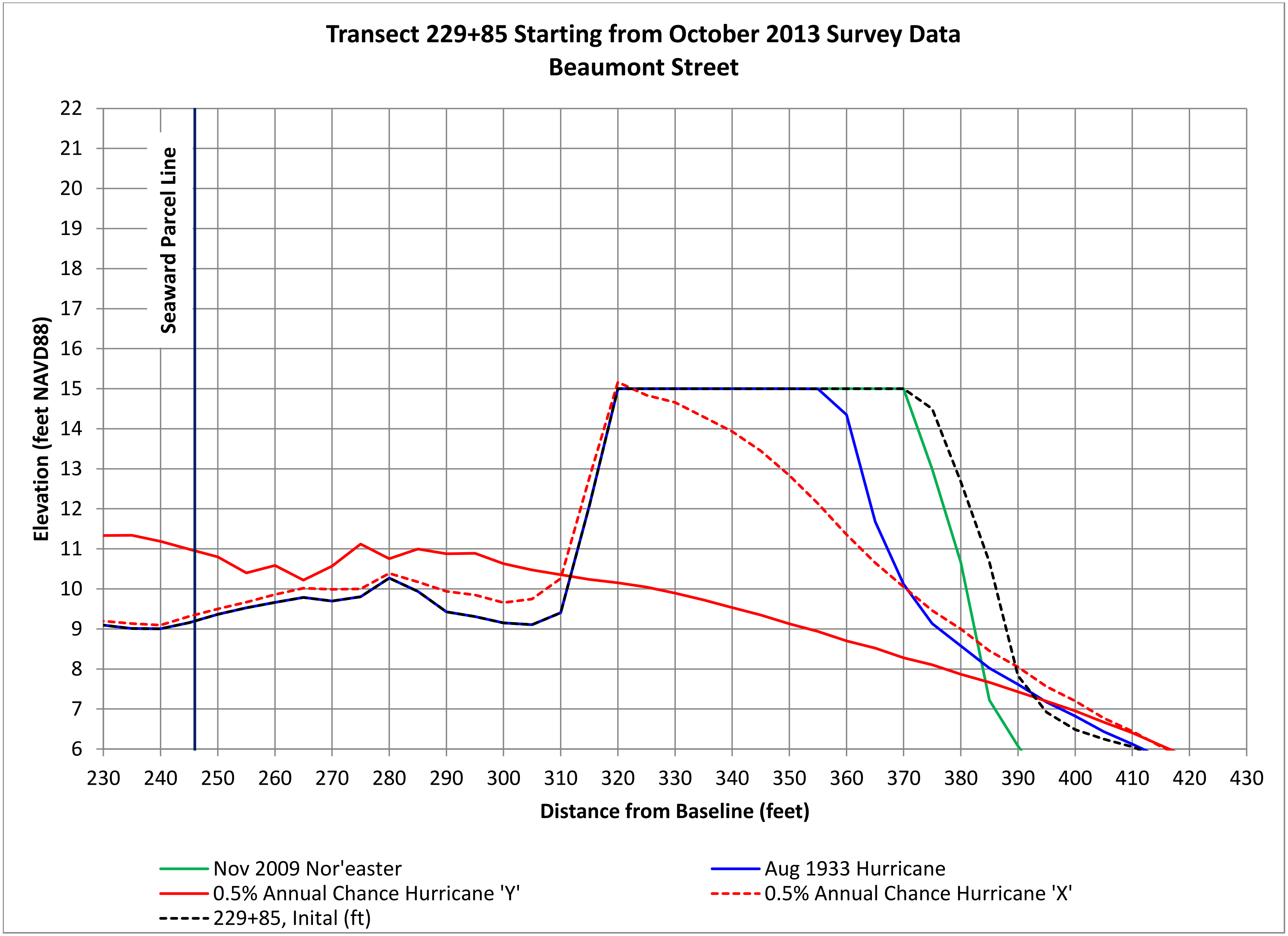

Transect 281+40 Starting from October 2013 Survey Data
3rd Bay Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
430
440
450
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
281+40, Inital (ft)

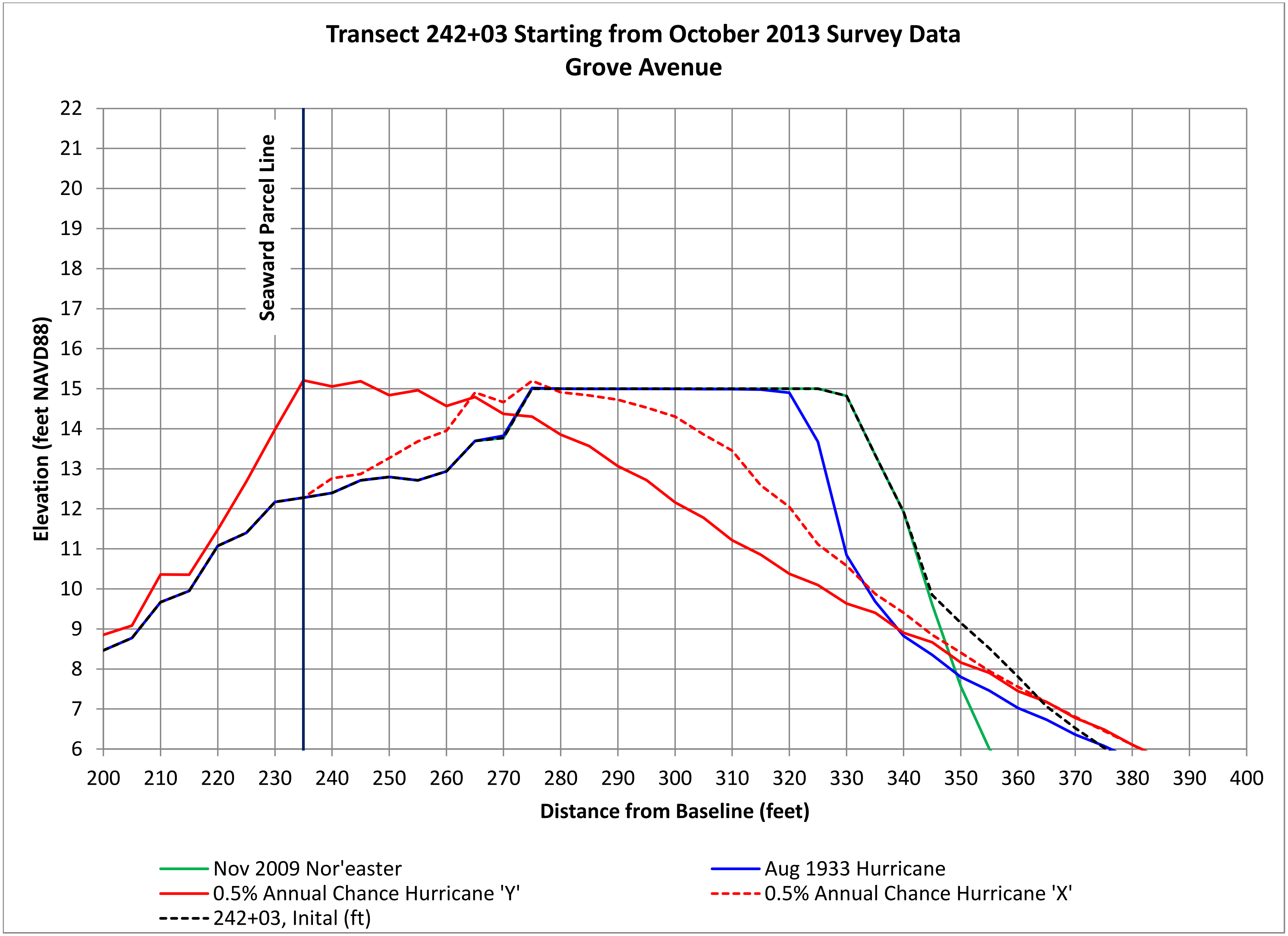
Appendix F: SBEACH Storm Erosion Results, +15 ft NAVD88 Maximum Dune Crest Elevation

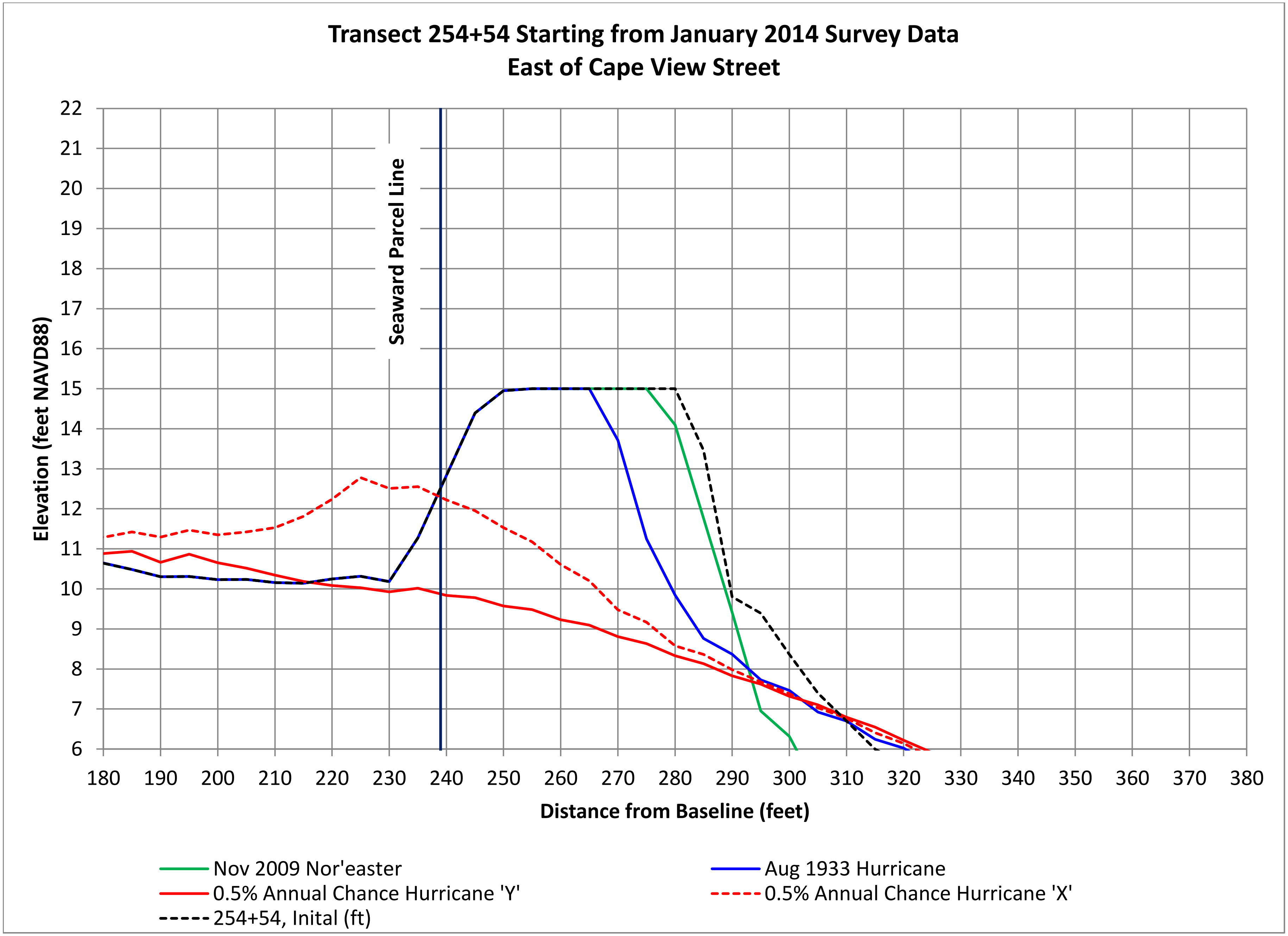

Transect 206+86 Starting from October 2013 Survey Data
Beach View Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
155
165
175
185
195
205
215
225
235
245
255
265
275
285
295
305
315
325
335
345
355
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
206+86, Inital (ft)

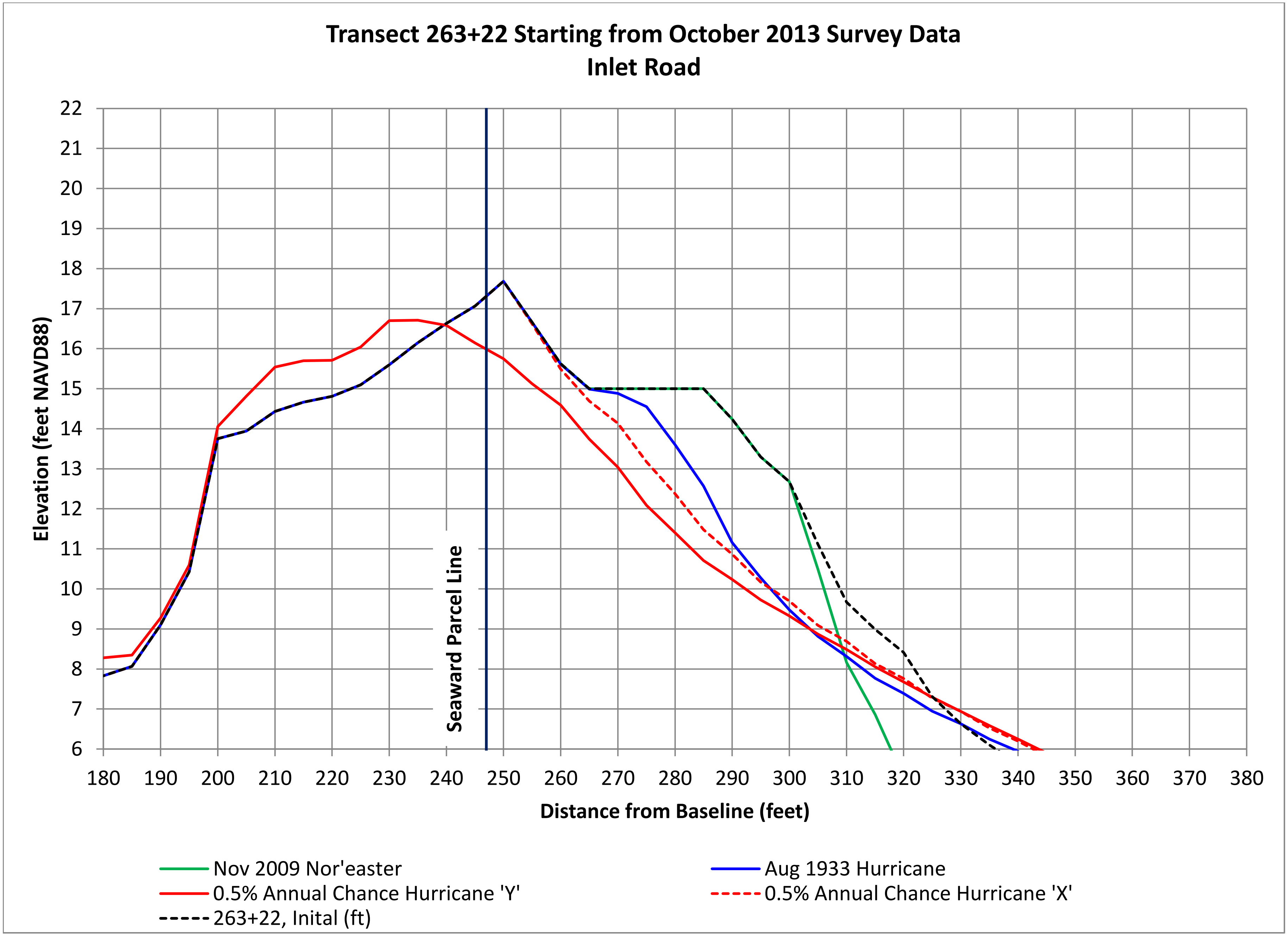


Transect 218+66 Starting from October 2013 Survey Data
Sturgis Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
218+66, Inital (ft)

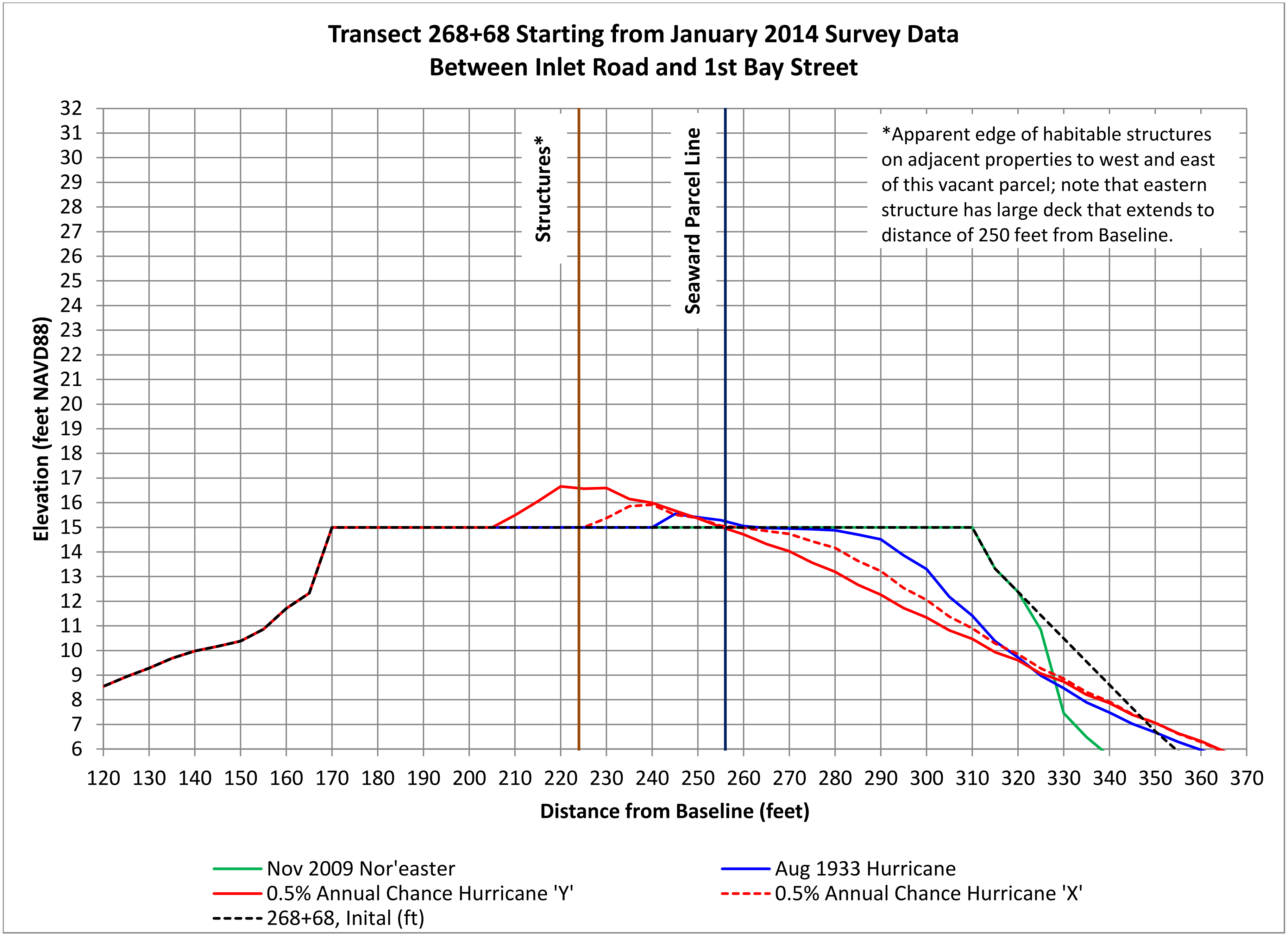

Transect 229+85 Starting from October 2013 Survey Data
Beaumont Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
430
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
229+85, Inital (ft)

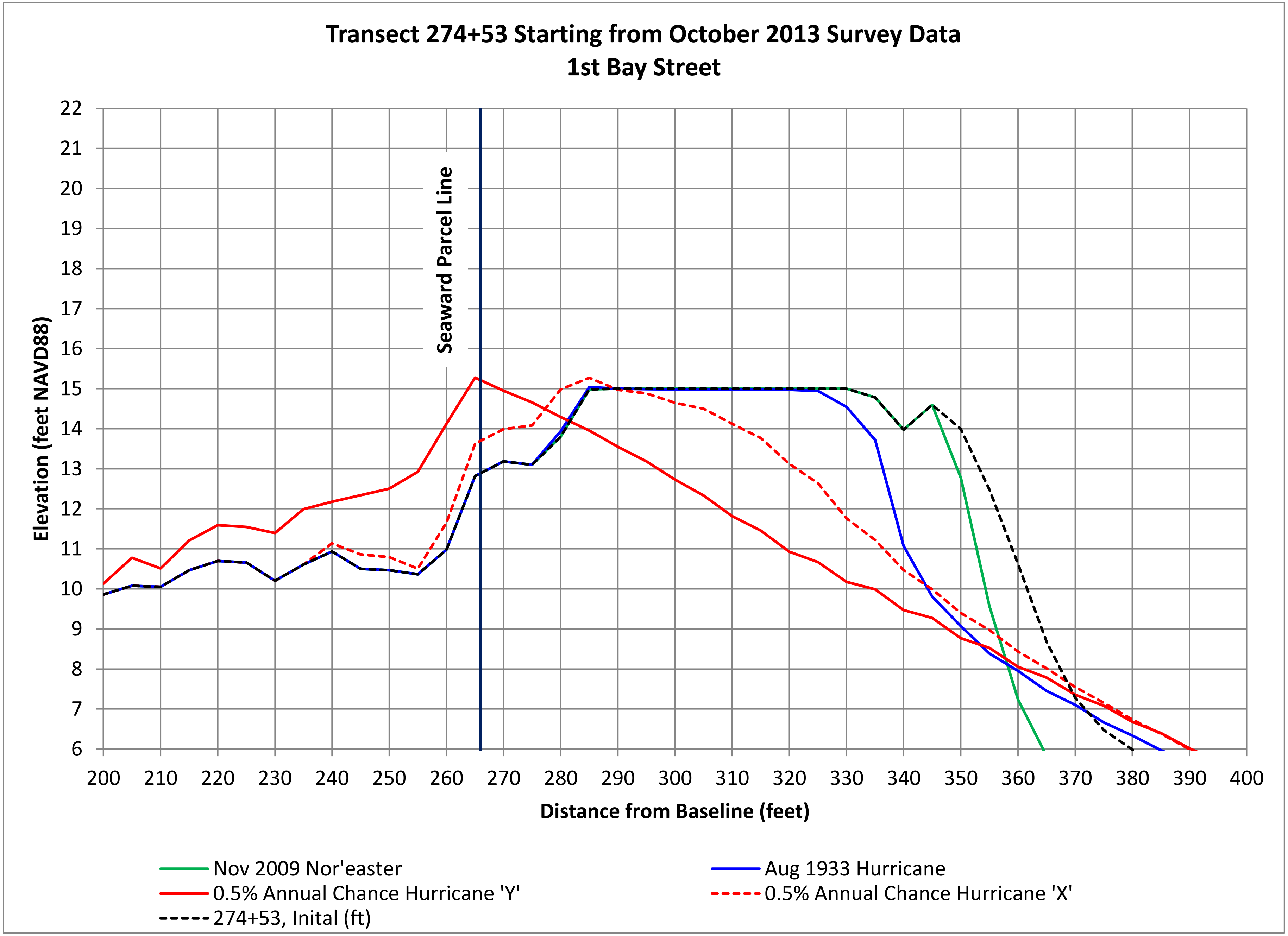

Transect 242+03 Starting from October 2013 Survey Data
Grove Avenue
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
242+03, Inital (ft)

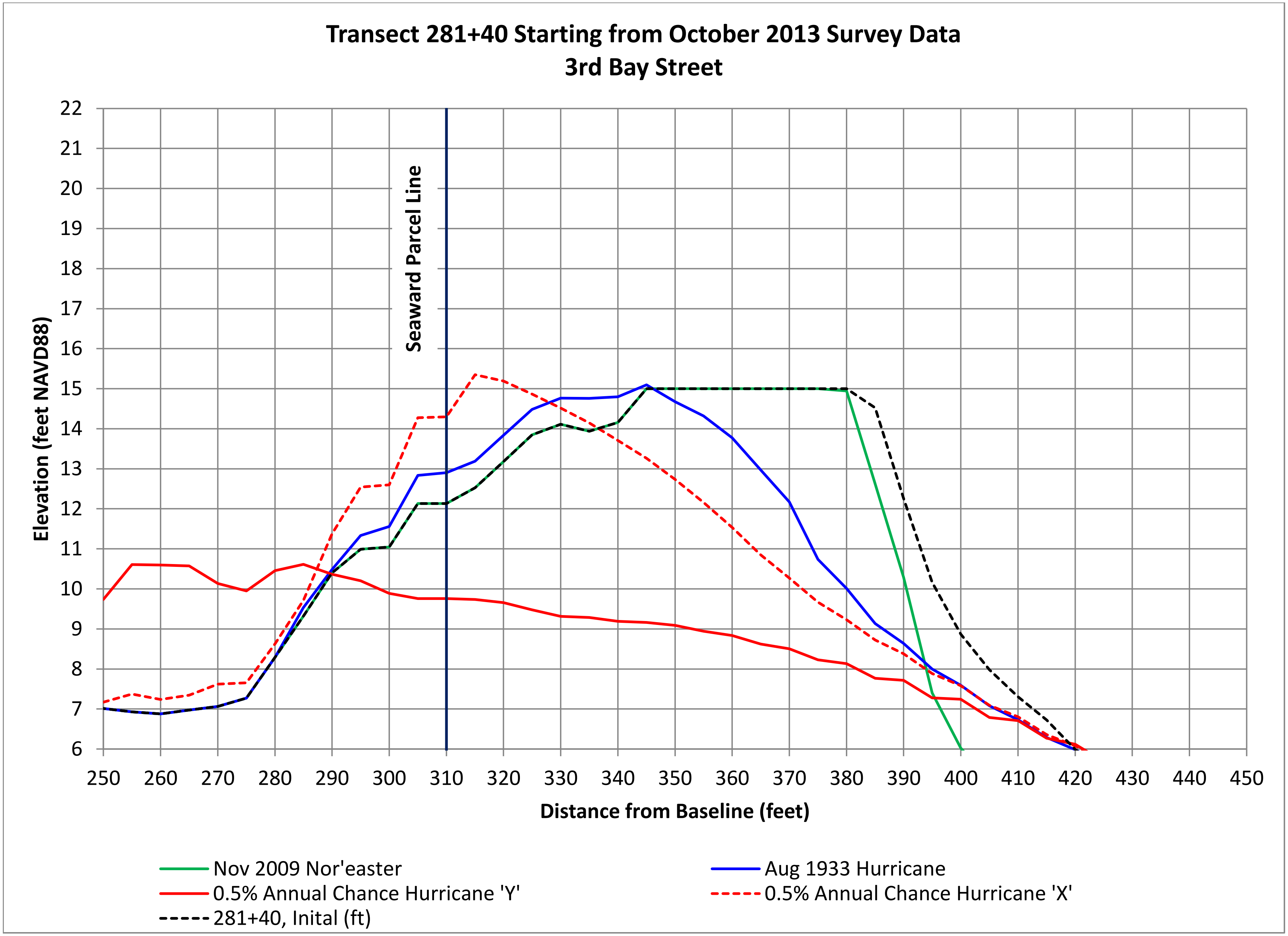

Transect 254+54 Starting from January 2014 Survey Data
East of Cape View Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360 370 380
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
254+54, Inital (ft)



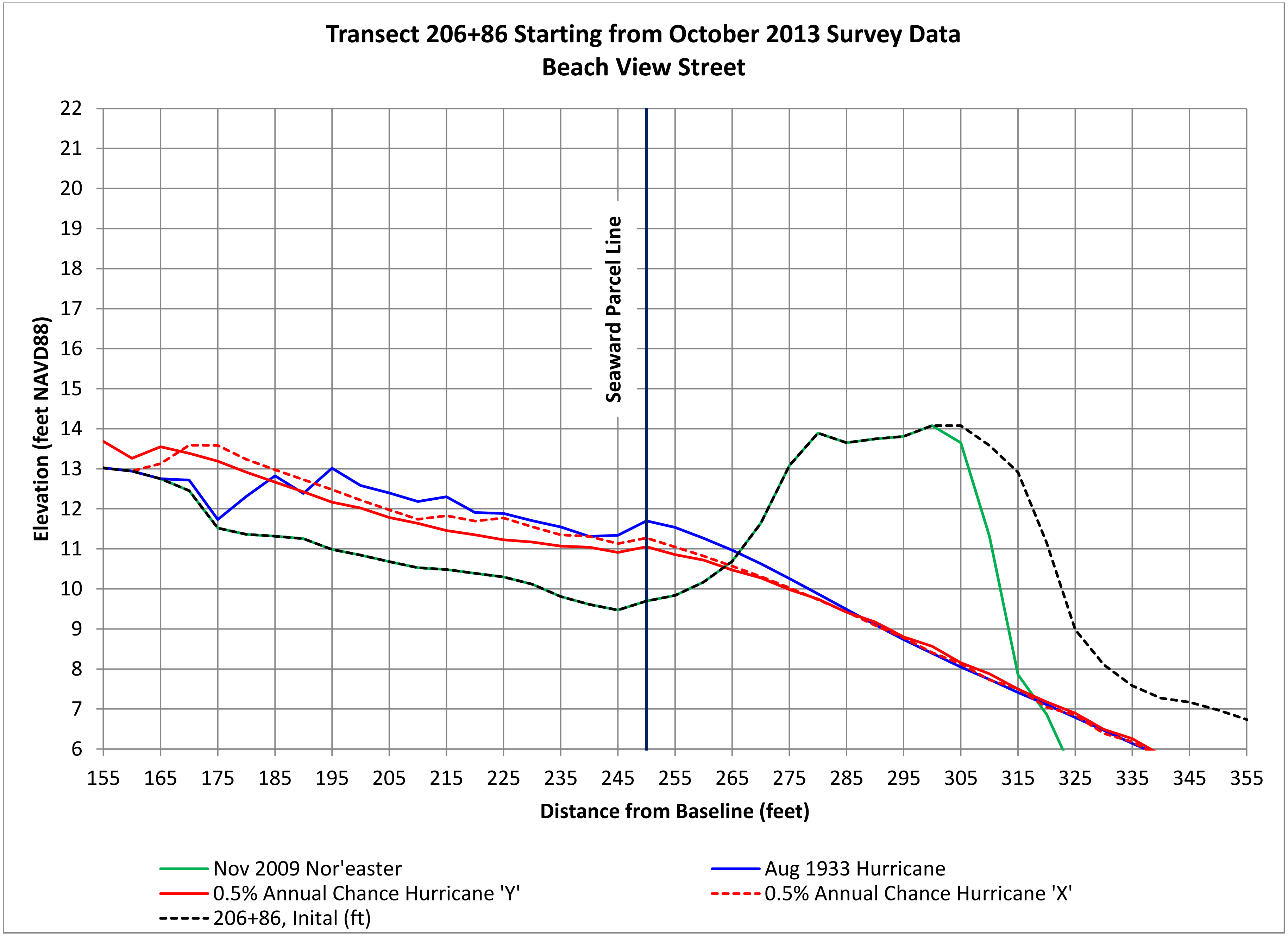
Transect 263+22 Starting from October 2013 Survey Data
Inlet Road
Elevation (feet NAVD88)
Distance from Baseline (feet)
Seaward Parcel Line
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
263+22, Inital (ft)

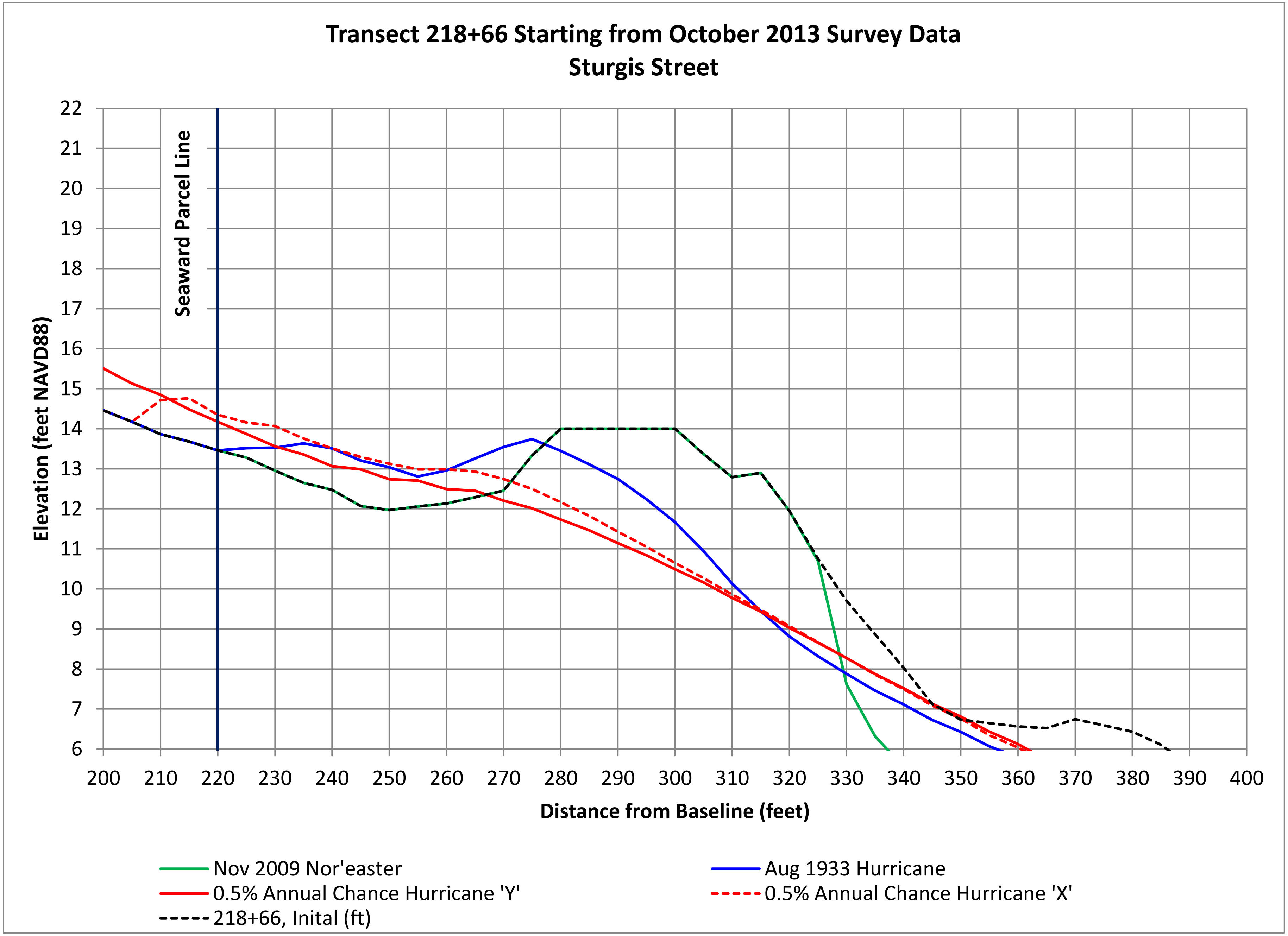

Transect 268+68 Starting from January 2014 Survey Data
Between Inlet Road and 1st Bay Street
Elevation (feet NAVD88)
32
31
30
29
28
27
26
25
24
23
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
Structures*
Seaward Parcel Line
*Apparent edge of habitable structures on adjacent properties to west and east of this vacant parcel; note that eastern structure has large deck that extends to distance of 250 feet from Baseline.
120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360 370
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
268+68, Inital (ft)


Transect 274+53 Starting from October 2013 Survey Data
1st Bay Street
Seaward Parcel Line
Elevation (feet NAVD88)
Distance from Baseline (feet)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
274+53, Inital (ft)

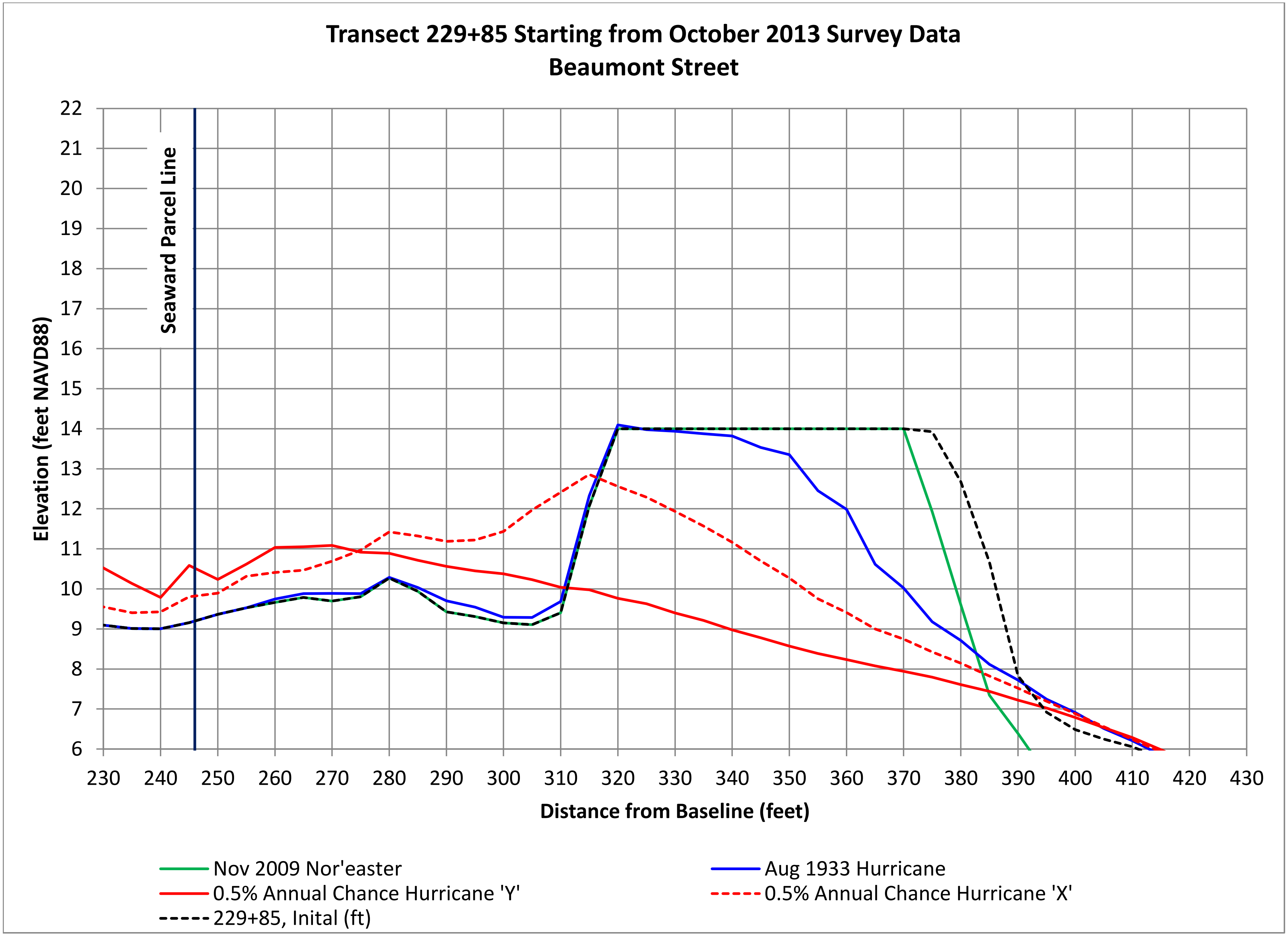

Transect 281+40 Starting from October 2013 Survey Data
3rd Bay Street
Seaward Parcel Line
Elevation (feet NAVD88)
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
281+40, Inital (ft)

Appendix G: SBEACH Storm Erosion Results, +14 ft NAVD88 Maximum Dune Crest Elevation

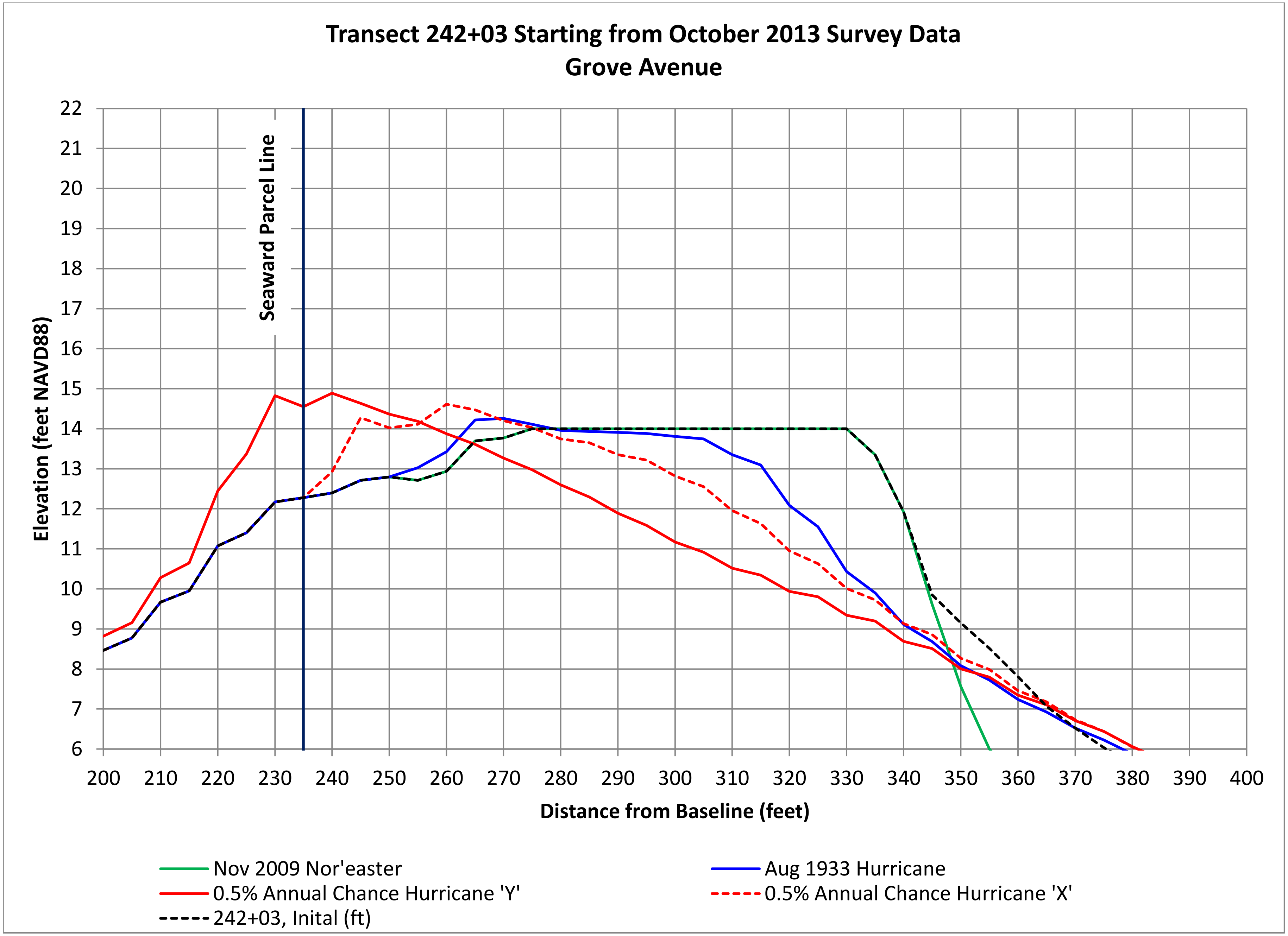

Transect 206+86 Starting from October 2013 Survey Data
Beach View Street
Seaward Parcel Line
Elevation (feet NAVD88)
Distance from Baseline (feet)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
155
165
175
185
195
205
215
225
235
245
255
265
275
285
295
305
315
325
335
345
355
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
206+86, Inital (ft)

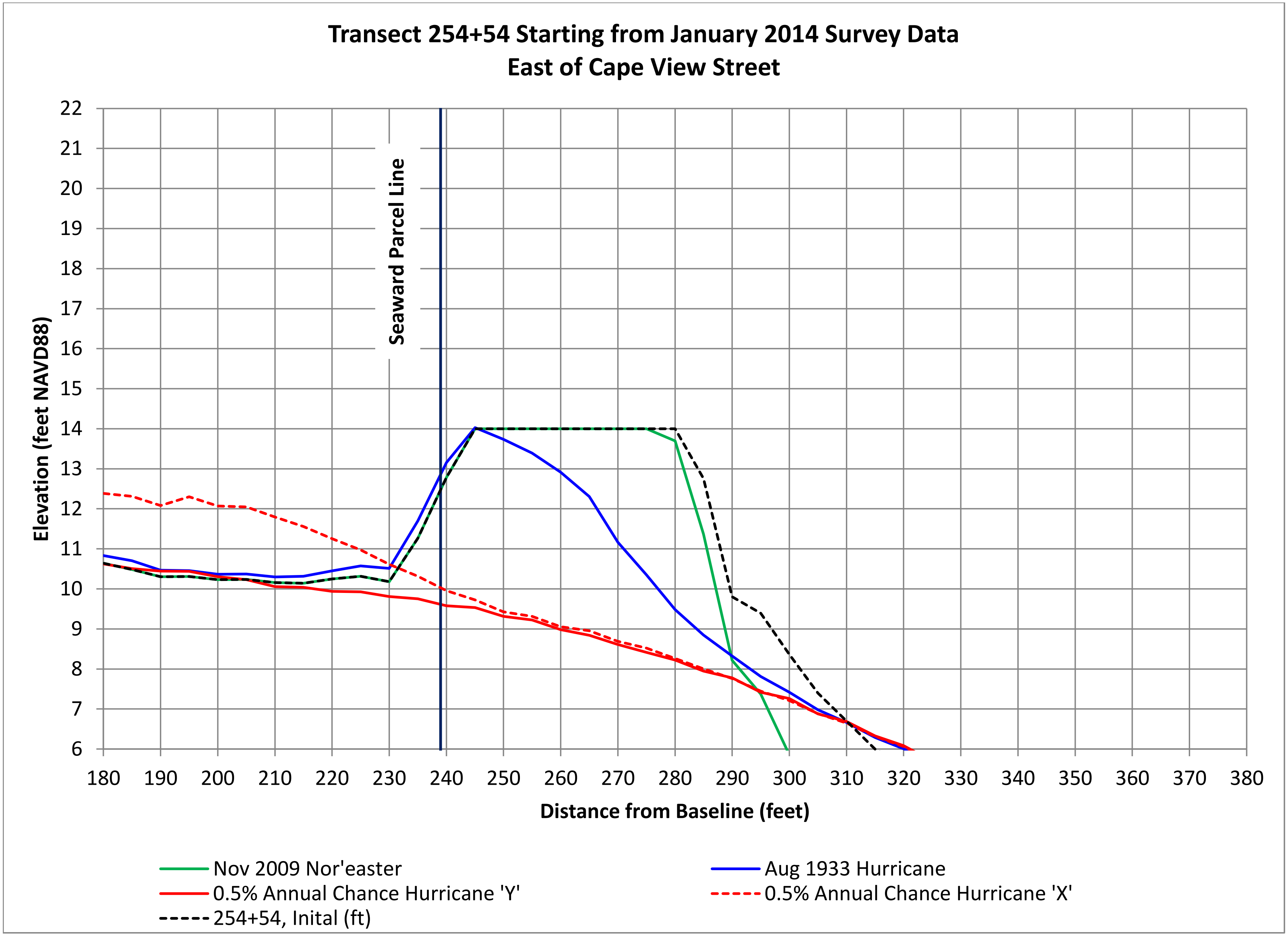


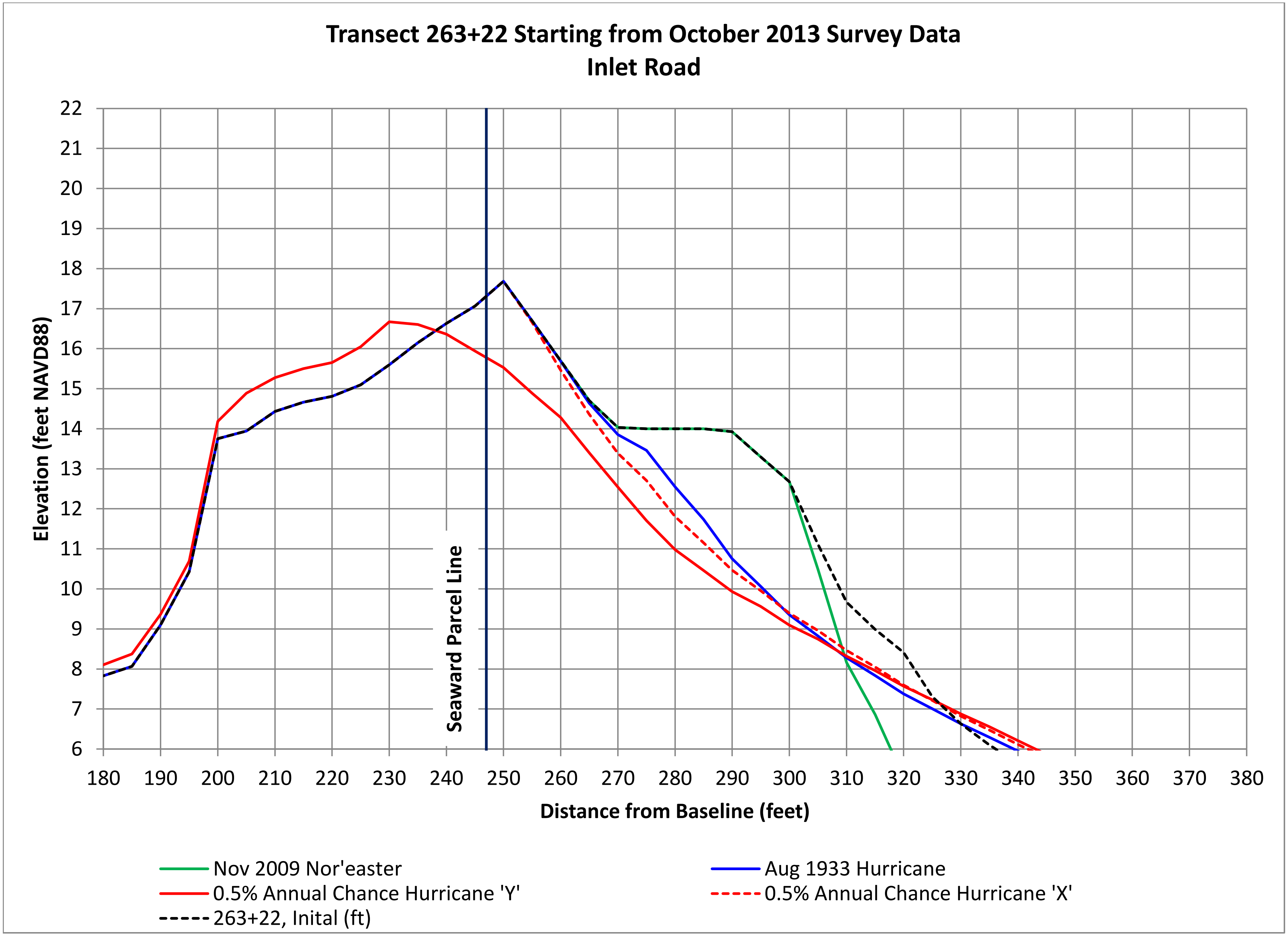
Transect 218+66 Starting from October 2013 Survey Data
Sturgis Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360 370 380 390 400
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
218+66, Inital (ft)



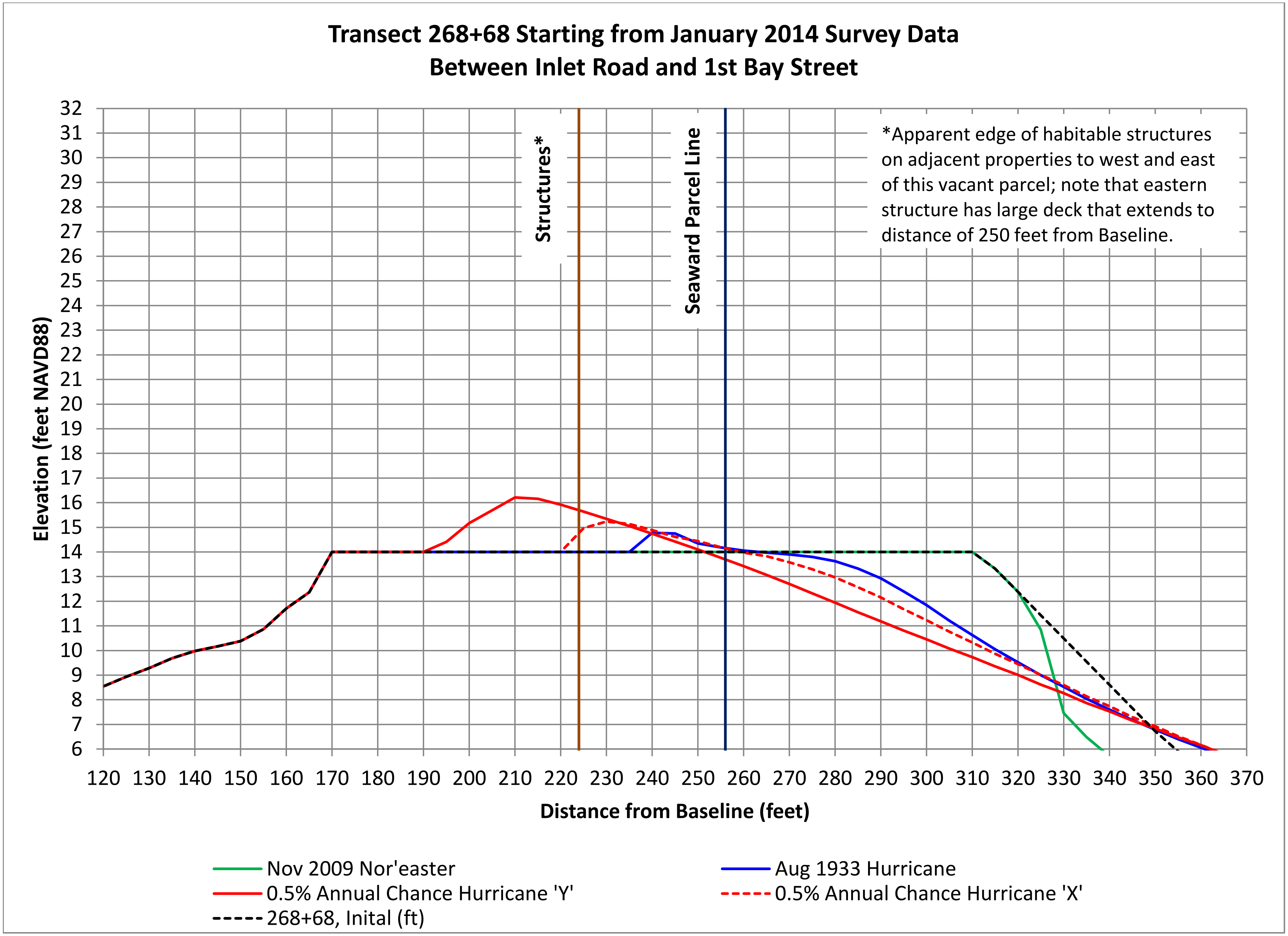
Transect 229+85 Starting from October 2013 Survey Data
Beaumont Street
Elevation (feet NAVD88)
Seaward Parcel Line
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
230 240 250 260 270 280 290 300 310 320 330 340 350 360 370 380 390 400 410 420 430
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
229+85, Inital (ft)


Transect 242+03 Starting from October 2013 Survey Data
Grove Avenue
Seaward Parcel Line
Elevation (feet NAVD88)
Distance from Baseline (feet)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
242+03, Inital (ft)

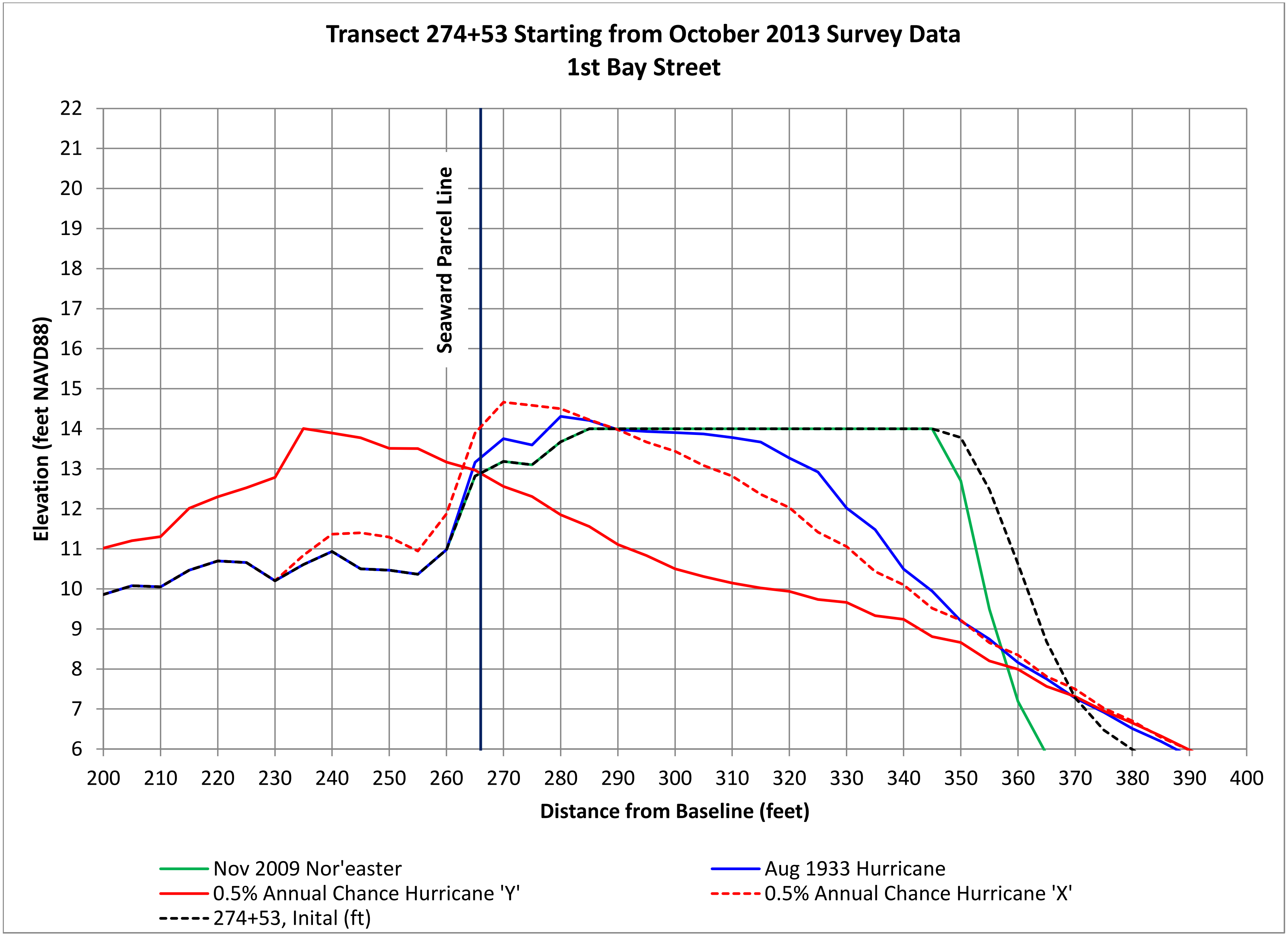

Transect 254+54 Starting from January 2014 Survey Data
East of Cape View Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
254+54, Inital (ft)

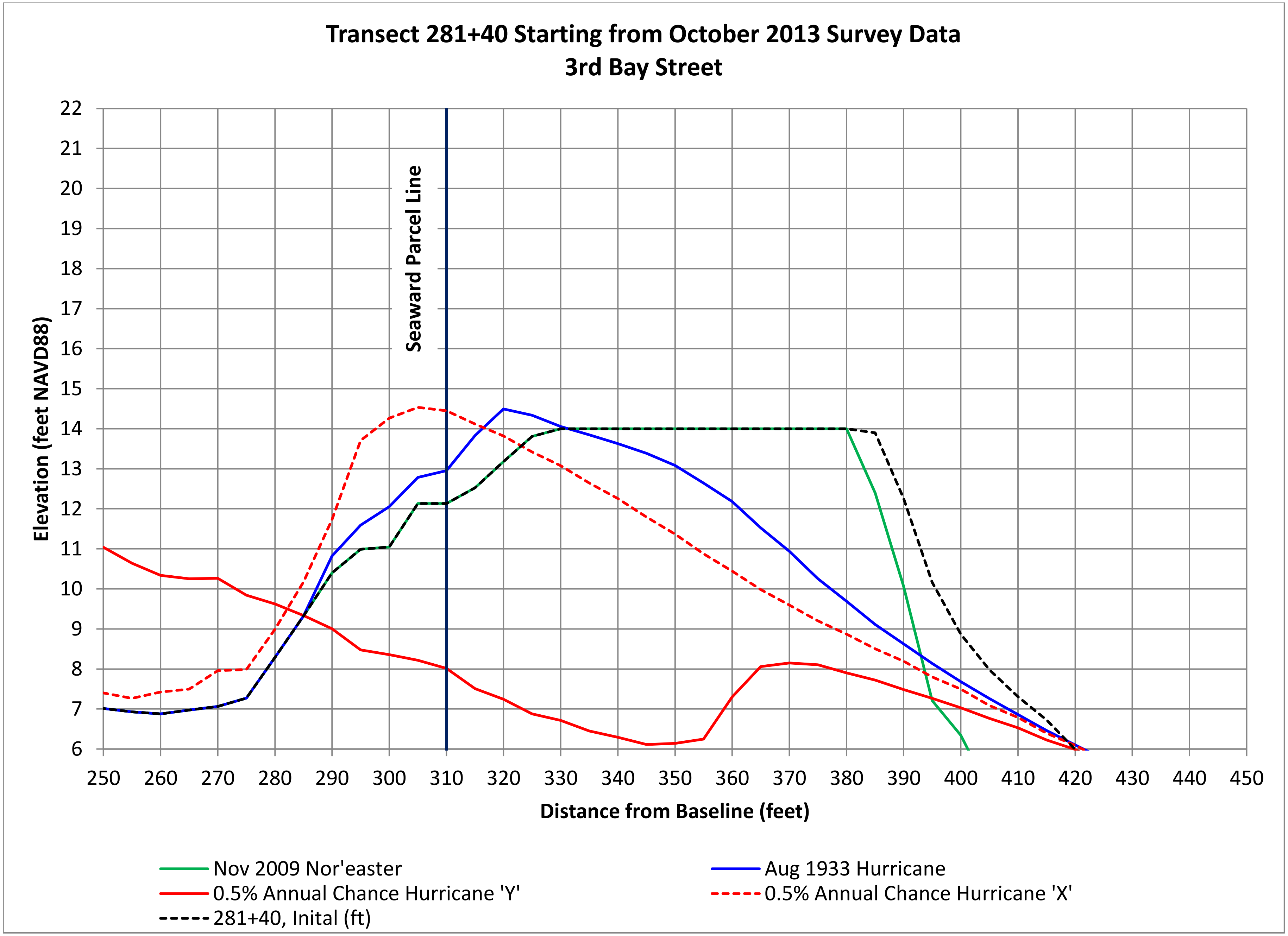


Transect 263+22 Starting from October 2013 Survey Data
Inlet Road
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
Seaward Parcel Line
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
263+22, Inital (ft)



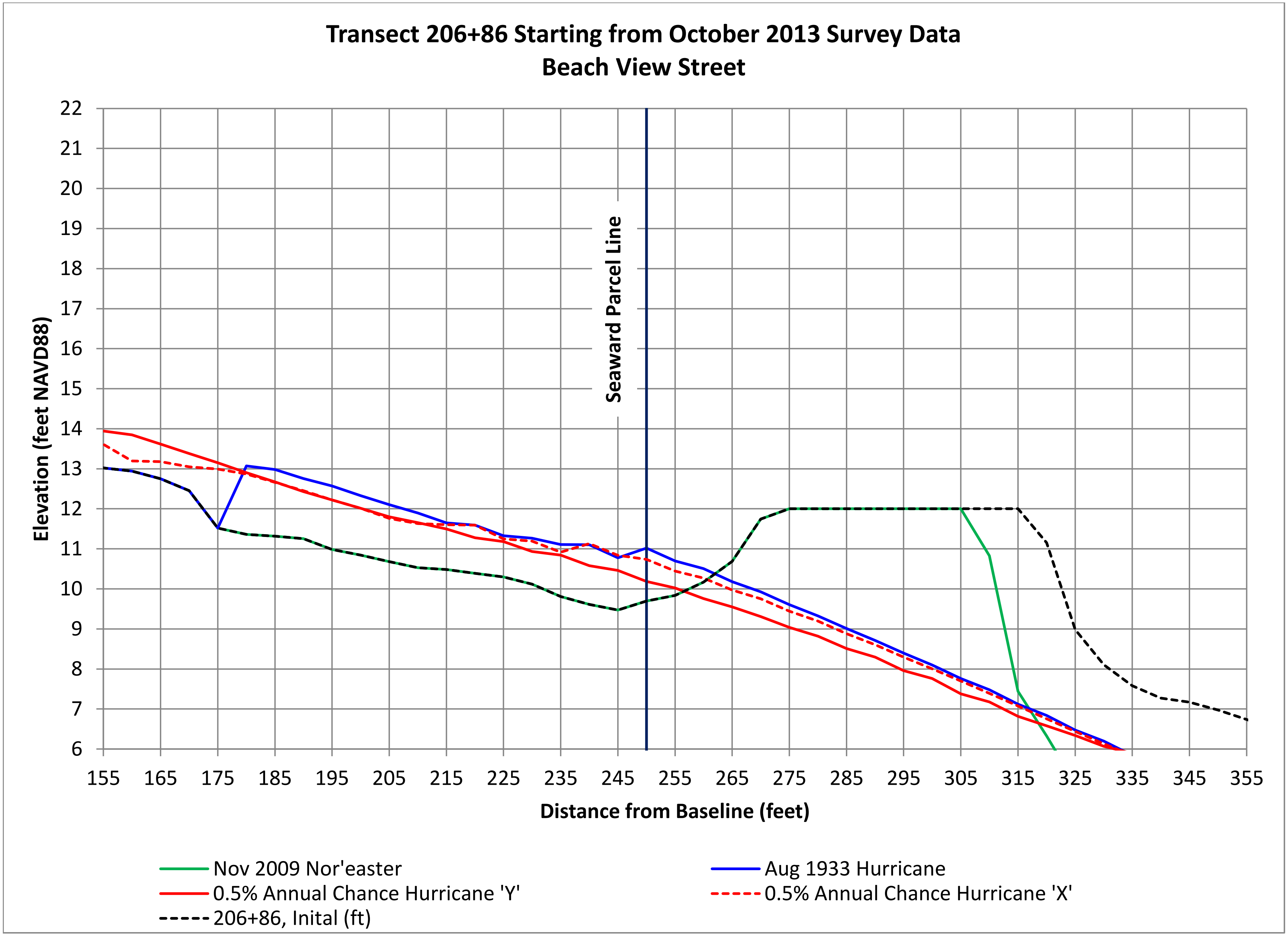
Transect 268+68 Starting from January 2014 Survey Data
Between Inlet Road and 1st Bay Street
Elevation (feet NAVD88)
Distance from Baseline (feet)
Structures*
Seaward Parcel Line
*Apparent edge of habitable structures on adjacent properties to west and east of this vacant parcel; note that eastern structure has large deck that extends to distance of 250 feet from Baseline.
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
268+68, Inital (ft)

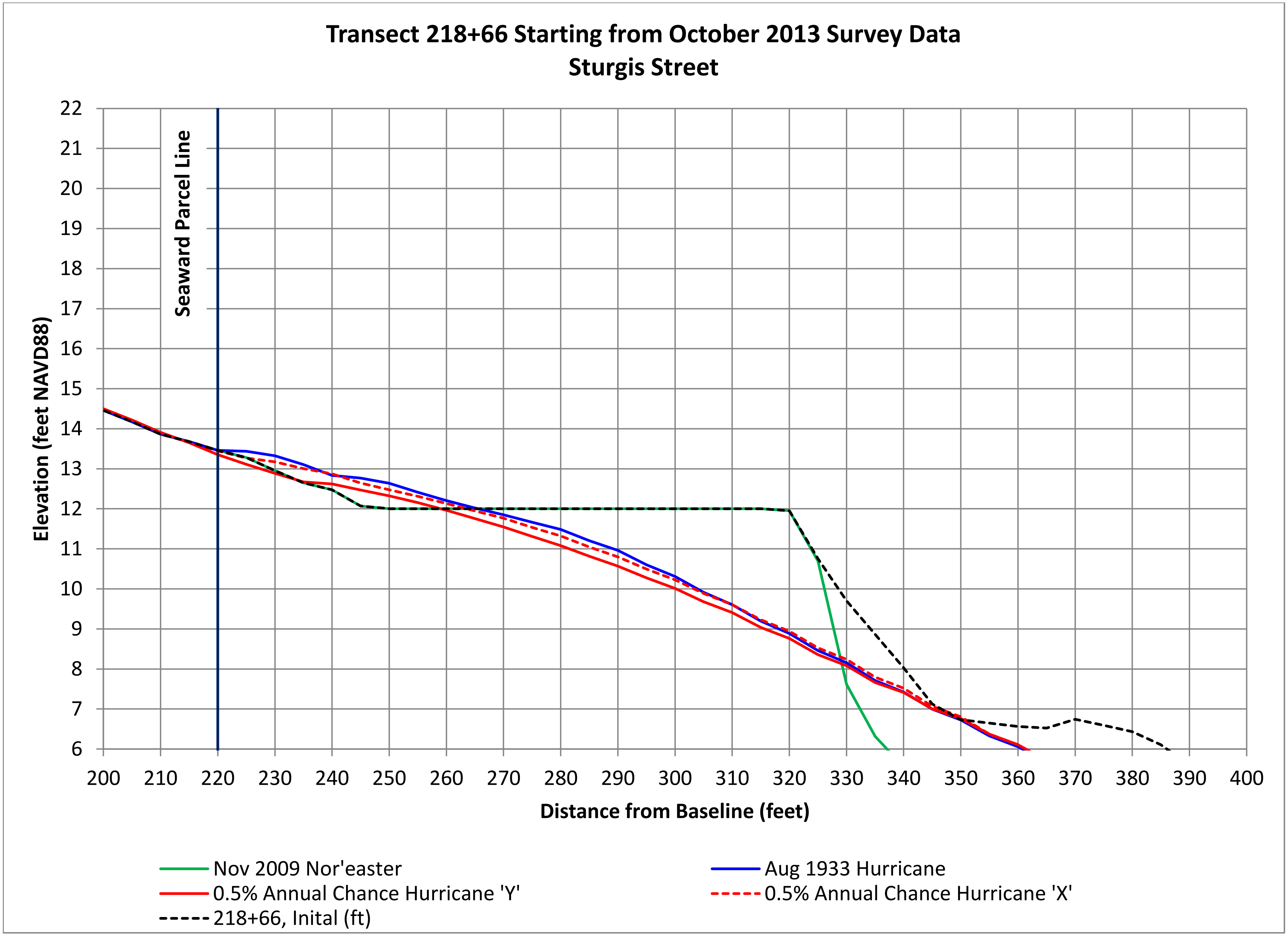

Transect 274+53 Starting from October 2013 Survey Data
1st Bay Street
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
Seaward Parcel Line
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
274+53, Inital (ft)

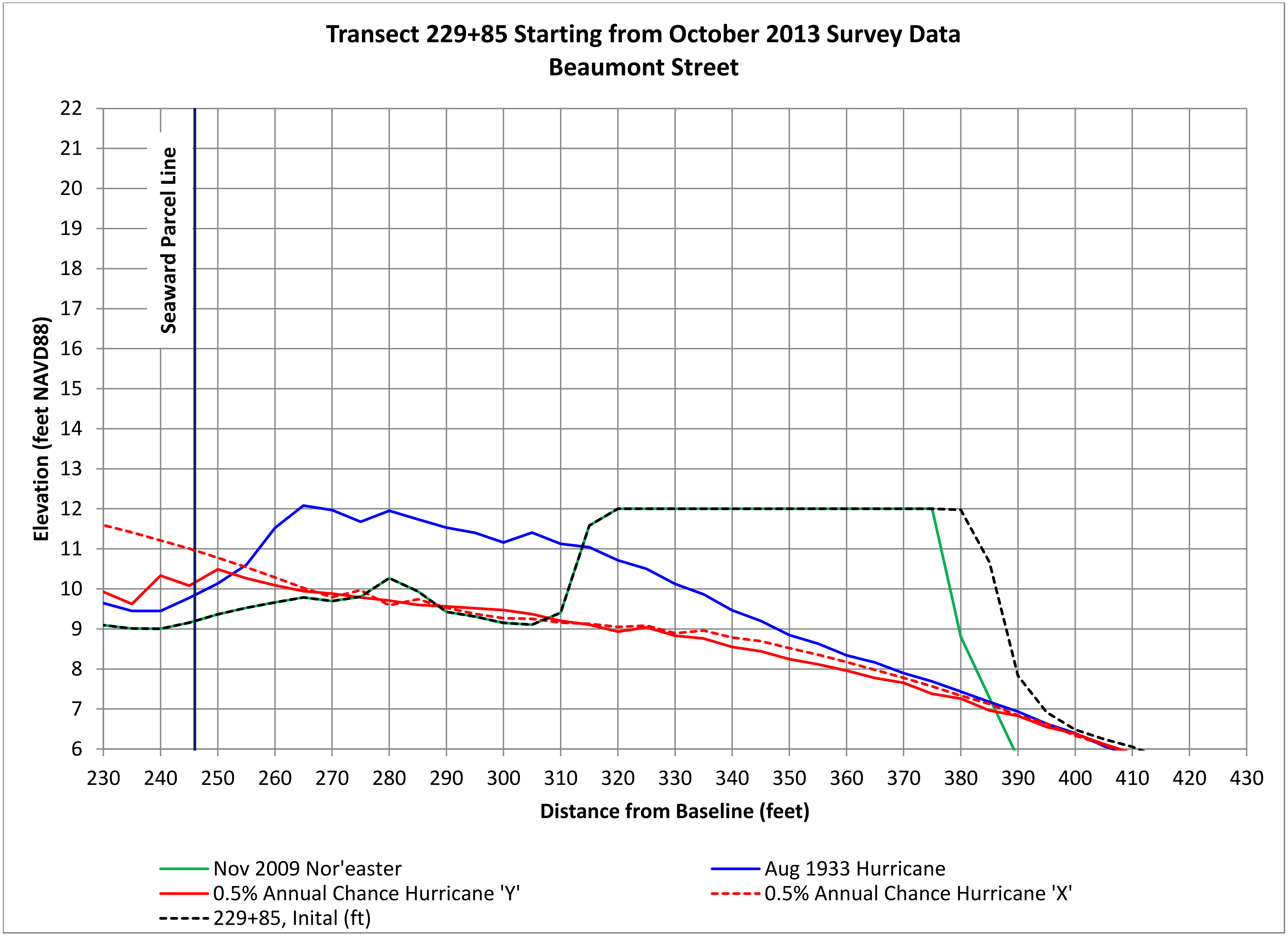


Transect 281+40 Starting from October 2013 Survey Data
3rd Bay Street
Seaward Parcel Line
Elevation (feet NAVD88)
Distance from Baseline (feet)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
430
440
450
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
281+40, Inital (ft)

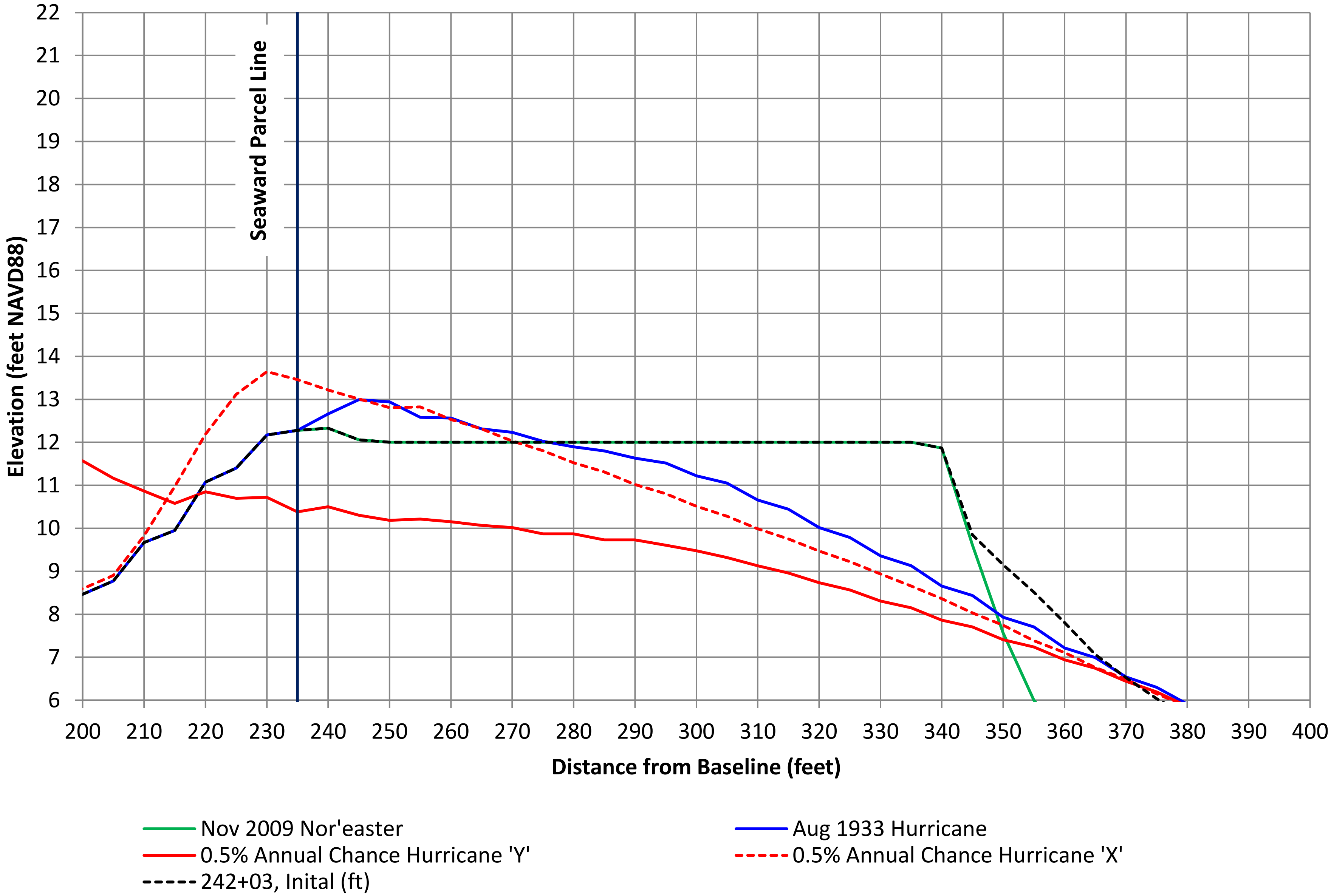
Appendix H: SBEACH Storm Erosion Results, +12 ft NAVD88 Maximum Dune Crest Elevation

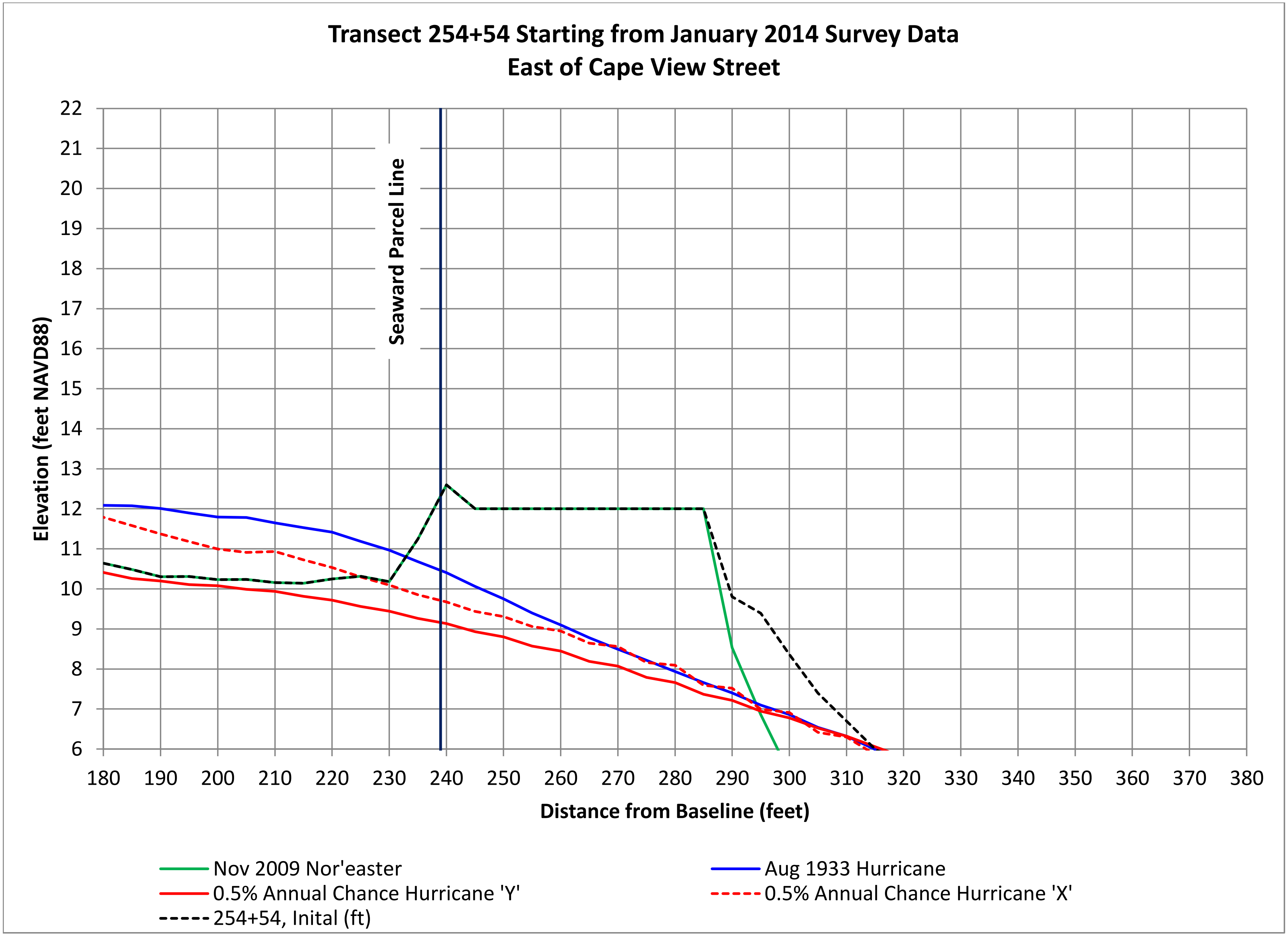

Transect 206+86 Starting from October 2013 Survey Data
Beach View Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
155
165
175
185
195
205
215
225
235
245
255
265
275
285
295
305
315
325
335
345
355
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
206+86, Inital (ft)


Transect 218+66 Starting from October 2013 Survey Data
Sturgis Street
Seaward Parcel Line
Elevation (feet NAVD88)
Distance from Baseline (feet)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
218+66, Inital (ft)

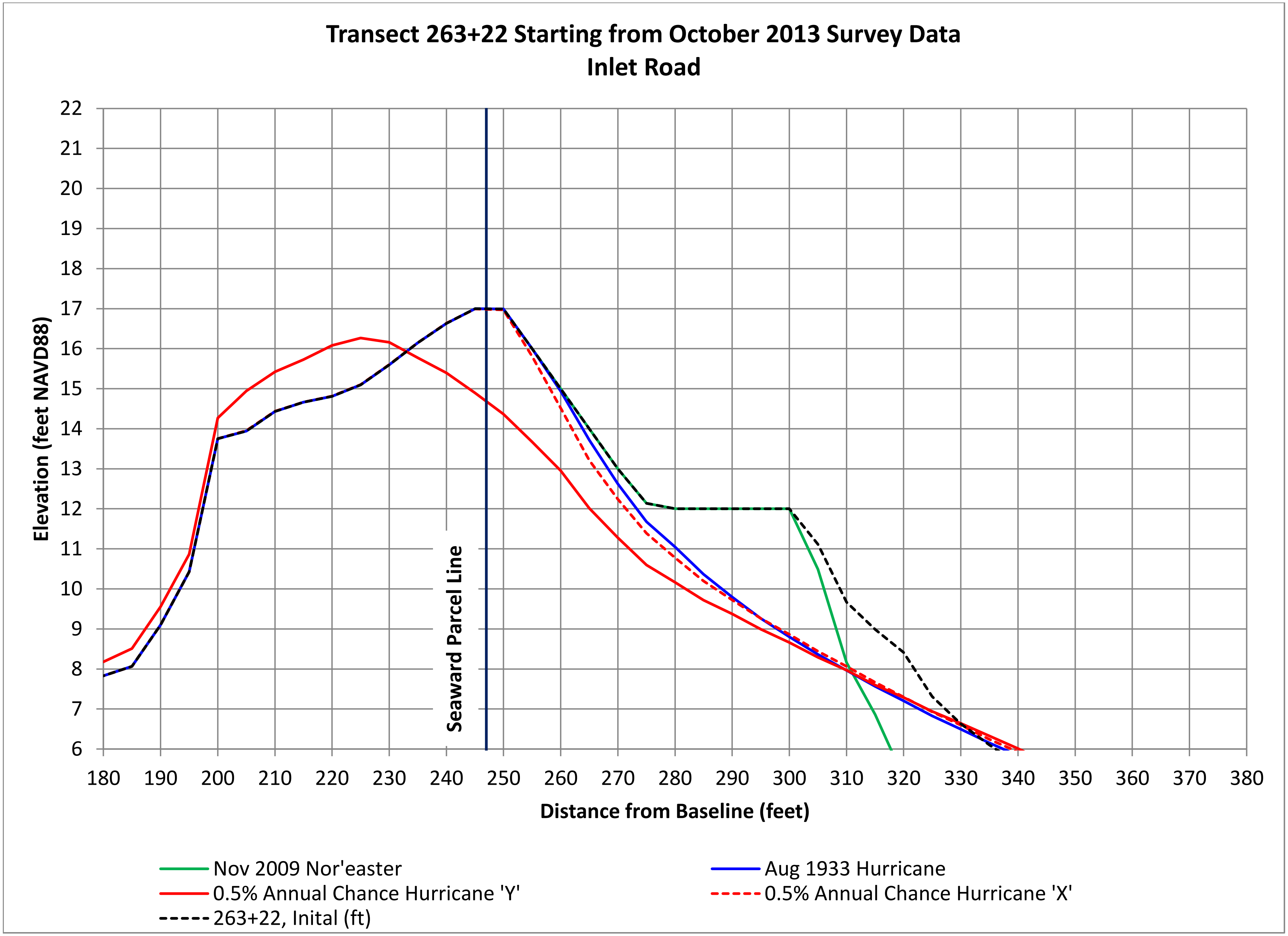

Transect 229+85 Starting from October 2013 Survey Data
Beaumont Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
430
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
229+85, Inital (ft)

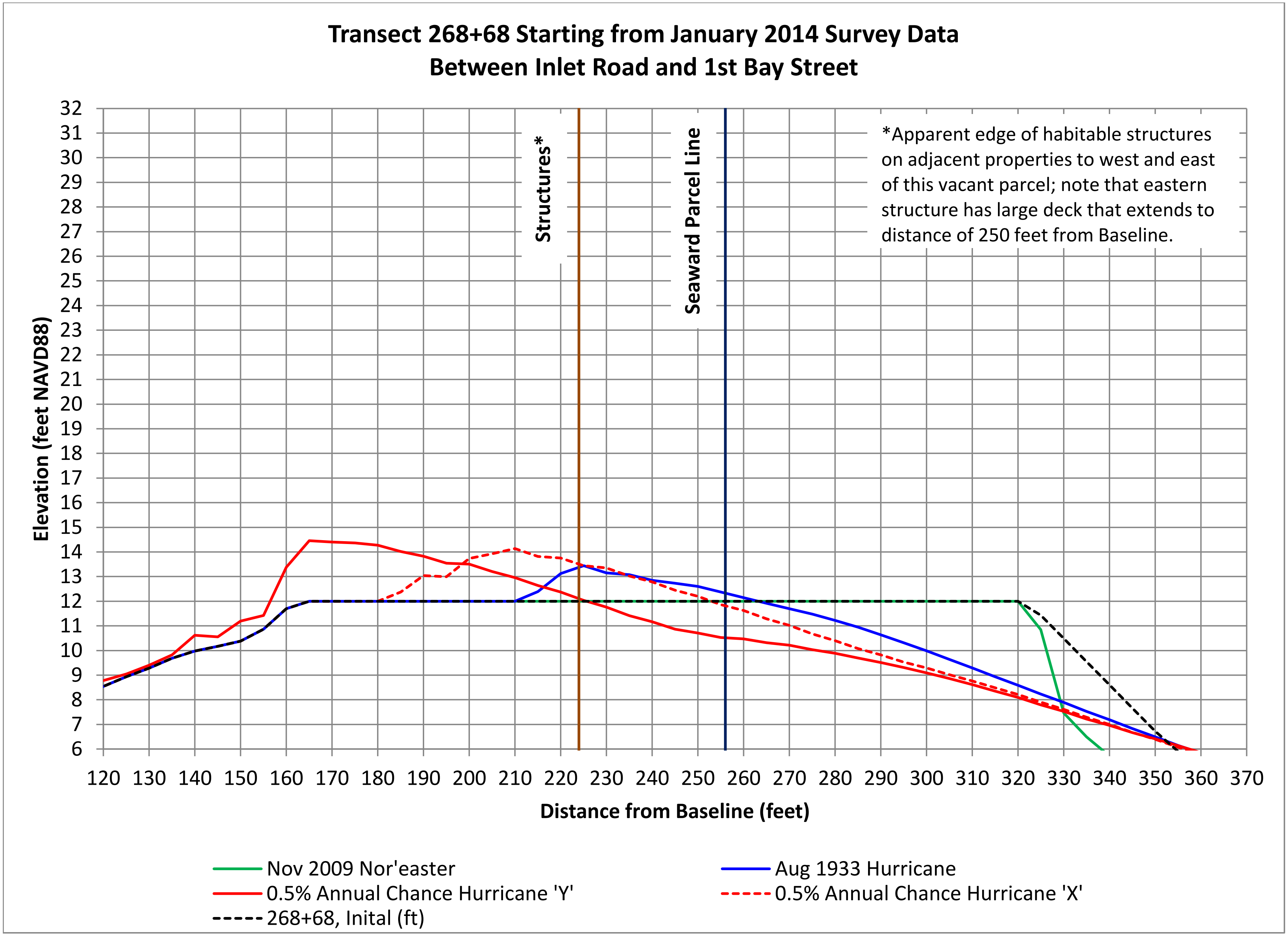
Transect 242+03 Starting from October 2013 Survey Data
Grove Avenue





Transect 254+54 Starting from January 2014 Survey Data
East of Cape View Street
Seaward Parcel Line
Elevation (feet NAVD88)
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
254+54, Inital (ft)


Transect 263+22 Starting from October 2013 Survey Data
Inlet Road
Elevation (feet NAVD88)
Distance from Baseline (feet)
Seaward Parcel Line
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
180
190
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
263+22, Inital (ft)


Transect 268+68 Starting from January 2014 Survey Data
Between Inlet Road and 1st Bay Street
Elevation (feet NAVD88)
Distance from Baseline (feet)
Structures*
Seaward Parcel Line
*Apparent edge of habitable structures on adjacent properties to west and east of this vacant parcel; note that eastern structure has large deck that extends to distance of 250 feet from Baseline.
32
31
30
29
28
27
26
25
24
23
22
21
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19
18
17
16
15
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13
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11
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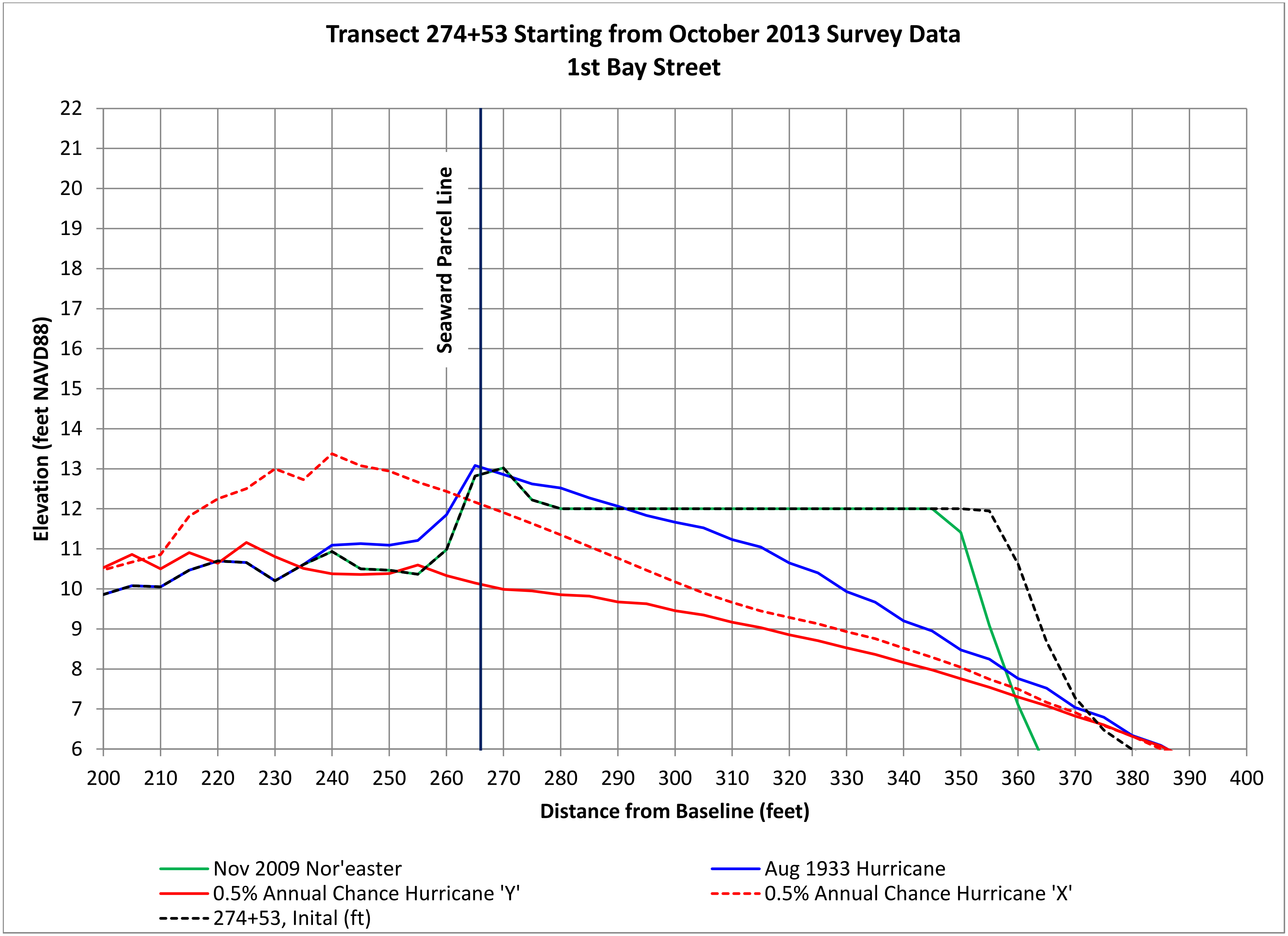
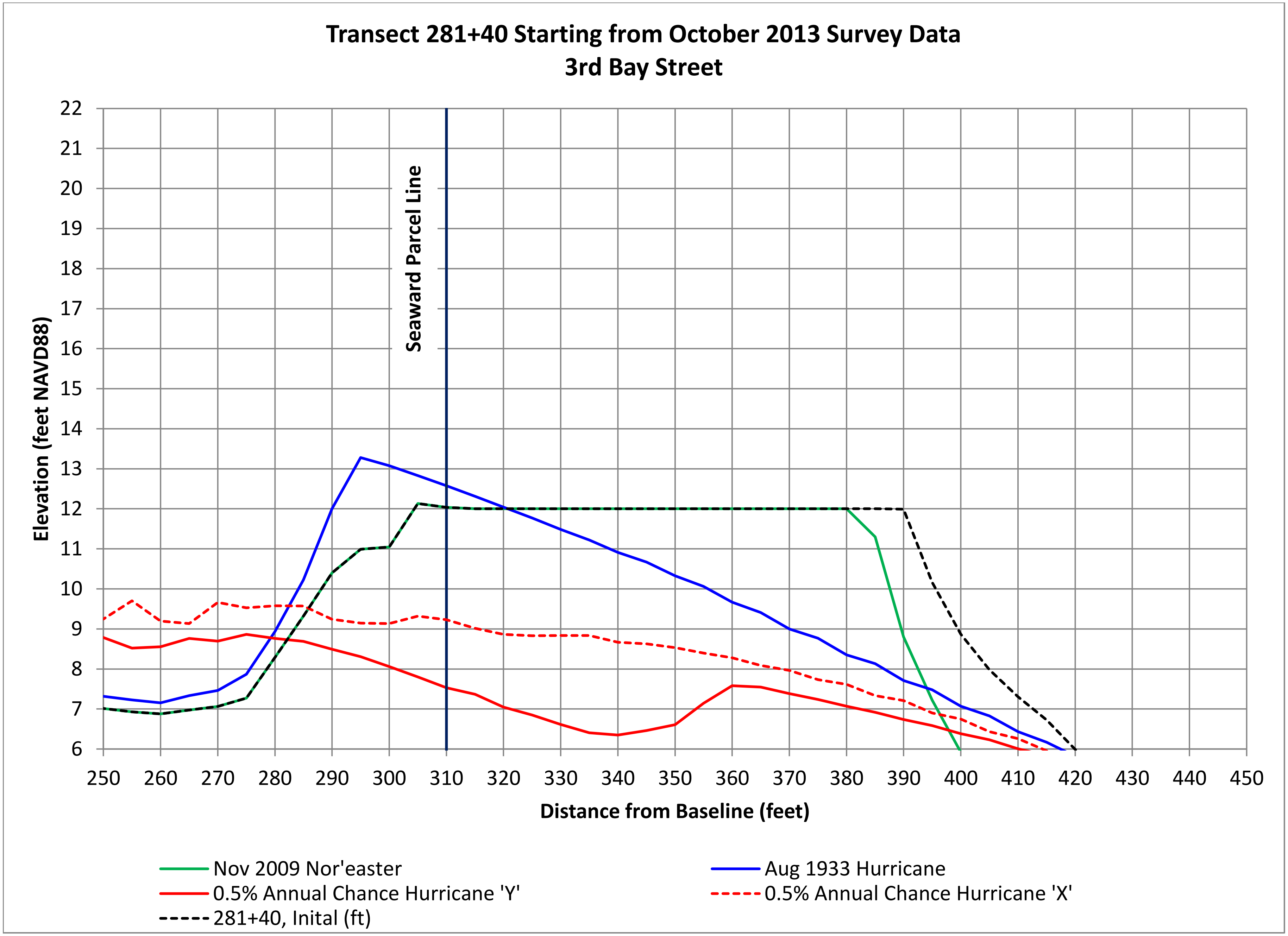
7
6
120 130 140 150 160 170 180 190 200 210 220 230 240 250 260 270 280 290 300 310 320 330 340 350 360 370
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
268+68, Inital (ft)


Transect 274+53 Starting from October 2013 Survey Data
1st Bay Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
200
210
220
230
240
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
274+53, Inital (ft)


Transect 281+40 Starting from October 2013 Survey Data
3rd Bay Street
Seaward Parcel Line
Elevation (feet NAVD88)
22
21
20
19
18
17
16
15
14
13
12
11
10
9
8
7
6
250
260
270
280
290
300
310
320
330
340
350
360
370
380
390
400
410
420
430
440
450
Distance from Baseline (feet)
Nov 2009 Nor'easter
Aug 1933 Hurricane
0.5% Annual Chance Hurricane 'Y'
0.5% Annual Chance Hurricane 'X'
281+40, Inital (ft)